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The Association between Residential Crowding and Asthma in Children in NHANES 2005-2006

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The Association between Residential Crowding and Asthma in Children in NHANES 2005-2006

By

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B.Arch, B.I.Arch.
Auburn University
2009

Thesis Committee Chair: Dana Barr, Ph.D.

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
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Abstract

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Context: Asthma is a chronic disease affecting the respiratory system and characterized by airflow obstruction and bronchial hyperresponsiveness. Exposures to certain risk factors for asthma stemming from the indoor environment have been documented to both exacerbate and increase risk of the disease. Several studies suggest the association between crowding and asthma is either null or inversely related. However, these studies use a myriad of definitions for calculating density and show even more variation when setting threshold levels of density for establishing crowding.

Objectives: Our objective was to review the multitude of methods for calculating crowding and to establish a method of calculating crowding that best relates the numerator and denominator to risk factors for asthma. We then hoped to establish a threshold value that is most representative of crowding in the population. Using these we related the prevalence of asthma to this new variable for crowding.

Methods: We identified 4,777 subjects under the age of 20 in the National Center for Health Statistics of the Centers for Disease Control and Prevention’s (NCHS/CDC) National Health and Nutrition Examination Survey (NHANES) two-year cycle from 2005-2006. We determined prevalence of asthma from interview variables and created a crowding variable from selected demographics collected on subjects. The density equation used for the study was people per room and the threshold for crowding was anything greater than or equal to the mean value for the population (mean=0.71). Odds ratios were examined using logistic regression procedures and accounting for weighting factors.

Results: Crowding was prevalent in 46% of asthma cases. Crowding was significantly associated with asthma in a logistic model adjusted for home age and subject age (OR=1.629, 95% CI: 1.054, 2.517).

Conclusions: The results of this study suggest that certain measures of crowding, such as the ones used here, may be associated with asthma while others may not. Many of the previous studies were conducted in countries that may not be comparable with one another so differences may be observed based on the population attitudes towards crowding. Further sensitivity analysis on multiple methods of calculating crowding and its associations with asthma may be warranted.

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Table of Contents

Introduction

Asthma prevalence in the United States is estimated to be at 8.2%, with a total of 24.6 million people affected [1]. One other factor that has been more recently associated with asthma is in-home crowding [2]. To show the relationship between crowding and asthma we must first determine the best method by which to calculate density within each residence and from this determine a threshold point for crowding [3]. The best equation will be the one that uses the denominator that best relates to risk factors for asthma [3].

What is Crowding?

'Crowding' has a multitude of definitions because each country and culture have different standards and expectations for how the residents of the country live [4]. In order to define crowding one must first determine density, a measure of how many people use a certain area [5]. From this measure cultural standards can be used to determine what is 'crowded' as opposed to what is not crowded [3, 6]. 'Crowding' naturally carries with it a negative connotation and is therefore an applied function of a certain density at which a culture or country has determined that the population within a given area will begin to suffer negative consequences [3]. An additional problem in defining crowding is that there are multiple functions by which population density can be determined although each comes with different arguments for and against its use [3, 7]. Table 1 is provided as a reference for definitions of density and thresholds for crowding in studies cited in this paper.

Often, when we refer to population density the calculation most commonly cited is that of total population per area of land [7]. This may be used most typically to generate the population density of a given city, country or continent [8]. However, having such a broad area of land in the denominator gives no indication of personal crowding [6]. Personal crowding is a measure of individual experience and likely has more affect on personal health than would the more general indicator of population per area of land [6]. Additionally, this general indicator has serious problems in that we may encounter one densely populated area next to one sparsely populated area [6]. If we were to capture both of these areas within our total area the two areas would effectively nullify one another resulting in the assumption that the total area is 'moderately populated' when in fact this is far from the truth [6, 8]. This equation could potentially by gerrymandered since the investigator can choose the denominator (in this case the given area) over which the population is being counted to make the area appear more or less crowded [9].

We could then take this equation and break it down into even smaller sections by using occupancy per building [10]. Occupancy per building is very commonly used in building codes to limit number of people both by dwelling unit and by square footage [11]. Crowding as a measure of building occupancy is theorized to promote negative health consequences through increased negative and/or forced social interactions [10]. The drawbacks associated with this equation are A) that apartment buildings or dorms are naturally going to have a much higher residential population than single family homes, resulting in these types of dwellings being automatically ‘crowded’ despite the fact that the building is compartmentalized into living spaces for each group and B) that we must then decide whether attached housing units such as town homes, where there are no shared spaces, count as high residential occupancy buildings or if they qualify as standalone homes for the purpose of crowding [10, 12, 13]. For these reasons it might be preferred to look at crowding as a per single family dwelling equation (whether attached or separated) rather than by buildings or by area.

However, there are further issues to consider when assessing crowding via single family residence data. We could determine density by calculating the occupancy rate, a measure of number of people per permanent private residences [3]. This equation is lacking because we have no indicator of the square footage of the household [3]. Given this drawback one alternative method would be to use people per square foot, an equation that is often used by prisons since these institutions often do not allow for single rooms [14]. If we were to proceed with using the equation in which the denominator is square feet we must then consider what area is acceptable per person and whether this square footage meets the requirements for privacy in a given culture [3]. Yet another method is to consider people per room, although if we are to use this equation we must then decide what constitutes a ‘room’ in which people live [3]. If we consider people per room we are now allowing for some measure of privacy since a given room is defined by walls. This equation could potentially be limited to people per bedroom, a measure that may determine how much space we share only during those times we occupy our sleeping quarters, or rooms could be defined as total household rooms, a measure of how many total livable rooms are shared between occupants [15]. If total livable rooms is the chosen measure, we must decide whether to include rooms such as the bathroom which we visit only upon necessity [16].

Another method is to combine these measures. For example, assessment of crowding in some studies employs the number of people per square foot of bedrooms, which utilizes both total number of bedrooms and square footage of bedrooms [3]. We must consider, however, whether this measure is indeed contributing a measure of space relevant to the disease we wish to study [3, 15]. For example this measure might be most relevant when considering easily transmittable diseases, because if two people share close proximity to one another for several hours the disease may be passed more easily from one to another [15]. However, if we are to look at chronic diseases, these short bursts of close proximity when people occupy bedrooms might not be as relevant as total time spent in all rooms in a house where we are exposed to each other's daily activities like smoking or cooking [17].

The definition used by the World Health Organization, or WHO, to define healthy housing does indeed combine several of these measurement techniques [3]. The standard for the WHO says that there should a be a satisfactory number of rooms, serviceable square footage and capacity of enclosed area consistent with the dominant cultural norms of that locality so that living or sleeping quarters are not crowded [3].Tthey also continue by saying that there should be adequate privacy and separation not only between people, but also between people and domestic animals [3]. While this is a desirable goal it is a general guideline and so provides no concrete numbers by which to judge whether a household should be considered crowded.

The U.S. Center for Disease Control and Prevention (CDC), on the other hand, has more tangible requirements for stating whether a building is crowded [3]. The CDC's standard for the United States population is "more than one person per room" [3]. In the same year the Canadian Mortgage and Housing Corporation estimated that approximately 10% of the renter households in the United States met the standard for being considered 'crowded' although that report does not indicate the level of crowding for non-renter households [3]. The regulation also goes on to provide an average square footage per person of living space [3]. However, while the United States provides an actual concrete number by which to judge crowding, they give no reasons to support this cutoff, nor does the square foot area assigned to a person by the CDC's standard vary by gender or age [3]. Additionally, since the United States is often a blending of multiple cultures this fails to take into account the fact that many cultures prefer a large family group living under one roof and may not consider certain situations to be crowded [4]. We might also find in some cases that the opposite is true, and some groups prefer sparsely populated quarters [4].

Common Health Effects of Crowding

Crowding is commonly associated with several health affects including both physical and mental outcomes [3, 18]. One paper posited that three mechanisms exist by which crowding affects health: (1) social and behavioral restriction, (2) reduced control, and (3) excessive stimulation [19]. Crowding was found to be associated with such outcomes as suicide, increased conflict, drug abuse, and unemployment [20]. Crowding also seems to be particularly associated with infectious diseases, predominantly those of the respiratory system, although a few studies have looked at non-infectious diseases and their links to crowding [17, 18].

When a person lives in a crowded home they are more likely to engage in certain activities that can spread disease [3]. For example sharing a bedroom can increase transmission of disease both because of proximity or physical contact and because the two persons are more likely to touch shared objects which may retain germs [21]. Sharing any space with a carrier of a certain disease can result in more prolonged contact, giving more opportunity for those germs to spread [21]. Increased crowding can lead to decreased hygiene, another factor which may contribute to disease spread [3]. Increased contact with others and with airborne particulate matter created from sloughing skin cells may also contribute to ill health in crowded situations [22].

In shared spaces certain things are likely to affect an individuals' mental health or result in the type of exhaustion and stress which can weaken the immune system [17]. Having many people in one household may cause the residents to lose sleep when another resident within the household is noisy [3, 17]. Crowding may also lead to lack of privacy, another common stressor [17].

Some elements of housing that may be linked to increased or decreased crowding include the condition of the home, and the type of home [3]. If the home is in poor condition it may limit the occupants to using only one room, and the decreased sanitary levels this causes may also be linked to disease [3]. The type of home can indicate that space is limited and may thus be linked to both crowding and health [3]. Additionally, the type of home may also indicate increased building occupancy if the home is an attached home, such as an apartment, townhome or dorm [10]. Because walls in these homes are shared, certain housing characteristics such as increased insects, and mildew presence may be shared between neighbors thus also affecting occupant health [23].

Asthma

Asthma can be difficult to define as it is a disease that presents widely variable symptoms [24, 25]. The mainstays of asthma diagnosis include airflow obstruction and bronchial hyperresponsiveness, often brought on by underlying inflammation [24, 25]. While these underlying causes are not immediately noticeable there are several clinical symptoms that characterize asthma, these include: wheezing, difficulty breathing, coughing, and chest tightness although all these symptoms may be present with various severities [24]. Diagnosis of asthma can at times be complicated by the fact that these clinical symptoms often mimic other respiratory diseases [25].

Asthma is a chronic disease whose prevalence has been rising in recent years [26]. This increase may be due to several explanations including changes in the classification of the disease, better ability to detect disease by physicians, or an increased susceptibility or severity of asthma [26]. Additionally, having asthma may result in increased comorbidity from other diseases. In adults, commonly observed comorbidities include chronic obstructive airway disease (COAD)/chronic airflow limitation (CAL), allergic bronchopulmonary mycosis, paradoxical vocal fold motion, sleep apnea syndrome, mucus membrane and sinus inflammation, peptic esophagitis/gastric reflux disease, obesity, stress, and major depressive disorder [24]. In children common comorbidities include infection with respiratory syncytial virus (RSV), foreign-bodies in airways, chronic lung disease of infancy/bronchopulmonary dysplasia, fibrocystic disease of the pancreas, and obesity [24].

A person's susceptibility to asthma may depend on certain innate qualities such as their intrinsic immunity, gender, and genetics [24]. Some reports estimate that one-third of asthma cases may be due to a genetic predisposition for developing asthma [24]. Additionally, certain other factors may play a role such as the presence of other respiratory conditions and environmental factors like exposure to allergens, although this may be dependent on the type of allergen and the length or timing of exposure [24].

Several of these risk factors for asthma may be influenced by the homes in which asthma sufferers live [27]. For example, houses may have high levels of dust, or contamination with mold/mildew that may exacerbate asthma but that can also be risk factors for asthma development [28, 29]. These factors are more likely to be found in older homes of individuals with low socioeconomic status

(SES) [29]. Similarly those with lower purchasing power may be forced to live in more cramped conditions because of the inability to purchase adequate square footage to support the number of people occupying the home [15]. Living in cramped conditions may lead to elevated exposures to environmental tobacco smoke (ETS), increased exposure to household dust, and the allergens it contains, and increased exposure to infectious diseases carried by other household occupants, all of which are risk factors for asthma [24, 27, 28]. Some additional recognized risk factors for asthma that come from the home include exposure to cooking fuels or exposure to volatile organic chemicals (VOCs); many building materials are known to off-gas although these materials may be more likely to be present in new construction homes[27].

Literature Review

Crowding is thought to be a risk factor for asthma and as such, a number of studies choose to control for it in their models, but these studies did not examine the direct effect of crowding on asthma [3, 30]. Some studies also report an OR for the association between crowding and asthma though it was not the primary goal of the study to do so [27, 31-41]. To our knowledge, there is only one published study that has assessed crowding as the primary exposure of interest and its association with the prevalence of asthma [42]. However, there exists a second study that examined crowding and current wheezing [43].This second study was included since wheeze is an important symptom associated with asthma [24, 43]. While crowding may seem more likely to negatively affect asthma by increasing exposure to asthma risk factors, these last two studies have instead observed positive associations, with increased crowding associated with a lower prevalence of asthma [42, 43]. There have also been a few studies conducted with asthma and proxy variables for crowding [42]. Sample proxies include birth order, living with a sibling, and family size [42].

Of studies that reported assessing crowding on asthma, despite this not being the primary goal of the study, a majority of the associations were indicated to be null [27, 31-37]. There were eight studies that reported statistically insignificant associations between crowding and asthma [31-37]. Four other studies found significant results [38-41]. Both studies which found that crowding was associated with increased asthma were conducted in Iraq [38, 39]. The first found that crowding was associated with asthma ($p<0.001$), when crowding was determined by number of children in the house [38]. In this study the OR for 2-3 children living in the household as compared with the referent category of 1 child in the household was 1.73 (95% CI=1.33-2.230), but when the authors compared greater than 3 children living in the household with the referent category the OR was insignificant 1.13 (0.84 – 1.52) [38]. The second study done in Iraq found that when crowding was set at greater than 5 people the odds ratio (OR=1.65, 95% CI=1.1, 2.4) was significant, though marginally so [39]. Of the studies that showed inverse relationships between crowding and asthma the first found that un-crowded households, determined by 0.75 people/room, were more likely to be associated with prevalent cases of asthma [40]. An additional study also found a relationship between having fewer than 3 people in a household and increased prevalence of asthma [41]. Due to the issue of multiple methods for calculating crowding, many of these results are not comparable [3, 27, 31-41].

The study most similar to our current study was a case control study in Sao Paulo, Brazil that examined associations between crowding, asthma and lower respiratory infectious diseases [42]. The primary measure of density was calculated as the number of people in each child's bedroom and crowding was defined as being above the median population density [42]. Other measures of crowding were also assessed and produced results consistent with those of the primary measure [42]. When infections were distinguished from asthma the study found that crowding was concomitant with a 60% decrease in the incidence of asthma, however, the authors observed a 2 1/2 fold escalation in the occurrence of lower respiratory infectious diseases (p = 0.001) [42]. Additionally, the study authors stated that when using asthma as the outcome if infectious respiratory disease was not controlled for no association with crowding was observed [42]. The authors of the study point out that their findings are consistent with the hygiene hypothesis [42]. The hygiene hypothesis states that lack of exposure to infectious disease may increase prevalence of diseases like asthma and allergies [44]. This study was conducted in an environment that included shanty towns so it may not be representative of what we would expect to find in the US population [42].

The second study assessed predictors of wheeze and found that crowding was protective for wheeze in both preschoolers and primary-school age children [43]. No association between crowding and asthma was observed for several other exclusive groups assembled, including intermittent wheezers and persistent wheezers [43]. While wheeze does not necessarily indicate the presence of asthma it is an important symptom of the disease [24]. In this study density was calculated as the number of people per room, where room was limited to living rooms and bedrooms; crowding was considered to be greater than or equal to 1.5 people per room. The authors also stated their theory that siblings might be more likely to spread infectious diseases when crowding is present, and that having another respiratory disease might affect diagnosis with asthma [43]. The observed negative association between crowding and asthma in this study is also consistent with the hygiene hypothesis [42, 44].

Goals

The goal of this study is to examine the association between crowding and asthma in children less than 19 years of age. As such our hypothesis is: over-crowding is expected to be associated with increased asthma prevalence. Our aims are: to establish an appropriate method of calculating density as it relates to asthma, to determine levels at which crowding is occurring in a representative sample of the US populations (NHANES), and to relate this measure of crowding to asthma prevalence. From these aims we hope to make suggestions for future research and to make suggestions for setting threshold levels for crowding.

Methods

National Health and Nutrition Examination Survey (NHANES)

Data for this project were acquired from a continually-funded National Health and Nutrition Examination Survey (NHANES) which releases data in two year increments [45]. NHANES is designed to measure the health and nutrition status of the civilian, non-institutionalized U.S. population (CDC 2009). NHANES participants were selected based on their age, sex, and racial/ethnic background through a complex statistical process using the most current census information. Weighting variables in the dataset account for over or undersampling specific population subgroups [45]. For the current study, we utilized data from the years 2005-2006. The total sample size for this cycle was 10,348 subjects. Datasets from NHANES may contain only a portion of the total population from the cycle. The datasets used for this project are given in Table 2.

Inclusion/Exclusion Criteria

Data were limited to children and young adults in an effort to make the study population consistent and enable comparison with results of the two previous studies [42, 43]. Children and young adults were defined as those who were younger than 19 years of age at the time of the screening interview.

Exposure Variable

The exposure of interest was defined as occupying a crowded single family residential unit. After reviewing the multitude of methods by which other investigators have calculated crowding, a per room equation was deemed the most relevant measure by which to calculate density in the current study. The per room equation provides for some measure of each individuals privacy whereas a square footage measure may not indicate whether all the persons are sharing one room or each have their own space. Lack of privacy or separation is one of the theorized methods by which crowding takes a toll on human health. If we assume that each person has at least one room allotted to them, then they have a place, that at least at some point during their day, they could theoretically avoid coming into contact with another person. We therefore chose a per room, rather than per square foot method of calculating density. To create the person per room values for each observation two NHANES variables were used A) the demographic statistic which provided number of people in the household (DMDHHSIZ) and B) the question from the housing questionnaire "How many rooms are in this home, excluding bathrooms" (HOQ050). The first value was then divided by the second value to get the number of people per room.

We then established a crowding criterion that was different from the CDC's definition of one person per room, a standard that is far below normal for the typical American household [6]. As of only a few years ago, the average density within residences in North America was 0.5 persons per room [3]. In order to also take into account the general expected standard of living for U.S citizens the level at which crowding was set was determined by the mean density (x=0.71 persons/room, std. dev= 0.43 persons/room; Table 3) in the NHANES study population for the years 2005-2006. According to the Kolmogorov-Smirnoff test this variable is not normally distributed, however, the histogram (Figure 1) for the variable appears to show only moderate deviations from normality. We considered values above the mean to indicate conditions more crowded than the average household observed in this database.

Outcome Variable

The outcome variable was presence of asthma as determined via the variables "Has a doctor or other health professional ever told {you/SP} that {you have/s/he/SP has} asthma?" (MCQ010) and "{Do you/Does SP} still have asthma?" (MCQ035). An affirmative response to both questions resulted in the subject being classified as having asthma.

Covariates

Personal characteristic variables thought to be associated with both the outcome and the exposure variables include age race/ethnicity, body mass index (BMI) and Poverty income ratio (PIR). Age was stratified into pre/primary school ages (0-12 years) and middle/high school and college ages (13-19 years). The race/ethnicity variable utilized the same categories as the NHANES questionnaire and included Non-Hispanic White, Non-Hispanic Black, Mexican American, Other Hispanic and Other Race – Including Multi Racial. BMI percentiles were categorized into underweight, normal weight, and overweight.

Those who were underweight were those who were below the 5th percentile and those who were overweight were those at or above the 85th percentile [46]. Poverty to income ratio (PIR) is generated from comparing family income to poverty threshold, and was developed by the US Census Bureau as the federal poverty level measure (further information on poverty thresholds provided on the US Census Bureau's website) [47]. Subjects fell into the low category if their PIR was less than or equal to one, and into the high category if their income was greater than or equal to five, all remaining values were collapsed into the medium category to prevent over stratification [48].

Household characteristics considered were having an attached home, age of home, presence of cockroaches, and presence of mold/mildew. The type of home variable was dichotomized into detached or attached since this was considered to be the most likely characteristic of the home to influence asthma. Similarly age was dichotomized into homes built before 1960 and homes built in 1960 or later. Both mold/mildew and the presence of cockroaches were already dichotomous variables and as such no transformations were needed.

Additional covariates of interest were current/recent respiratory disease, current/recent pet in home, current smoking or tobacco use, exposure to passive smoking and exposure to VOC generating materials. These variables were all generated from combinations of several NHANES questionnaire variables. A summary record of NHANES variables used in this analysis and the methods for generating the final variables is given in Table 4.

Statistical Software Used

A combination of both SAS 9.3 (SAS Institute, Cary, North Carolina) and SUDAAN 11.0.0 (Research Triangle Park, North Carolina) were used to analyze data in correspondence with NHANES standards for data analysis. As instructed in the NHANES analytic guidelines, the statistical software SUDAAN was used to apply appropriate sample weights to the populations included in the analysis data set [45]. The SAS PROC SURVEY and SUDAAN PROC DESCRIPT were used to examine the data, and to check for extreme proportions of missing values. When determining whether missingness is extreme, two questions should be considered: (1) is there adequate statistical power in the remaining population and (2) is there a pattern to the missingness [49]. We set the cutoff for extreme missingness at <20% of a variable's observations [49]. Two variables exceeded this limit for extreme missingness, smoking, and home age, although the proportions of missing values was not differential with respect to cases and controls.

Analysis

Proportions of variables across cases and controls were compared using the chi-square test for dichotomous variables. We examined the association between living in a crowded residence and asthma using a multivariate logistic regression model (in SAS using PROC SURVEYLOGISTIC) controlling for expected confounders. A directed acyclic graph (DAG) was developed to determine if any potential variables related to both the exposure and outcome could be dropped from the model (Figure 2) [50]. Three possible covariates were dropped due to being intermediaries as a result of developing the DAG, these were VOC fumes, presence of cockroaches and passive smoking [50]. A minimal sufficient set to assess the total effect of crowding on asthma included whether the home was attached, home age, PIR, race/ethnicity, age, gender, and previous respiratory disease [50]. We also chose to keep the variable for smoking in the model since it is strongly associated with respiratory affects. Multicollinearity in this model was examined using the SAS collinearity macro adapted for use with the surveylogistic procedure [51]. The highest condition indices (CNIs) (>30) were examined first and variables with variance decomposition proportions (VDPs) higher than 0.5 were considered for removal from the model [52]. CNIs and VDPs are measures of correlation between variables and indicate that the effects of one variable cannot be separated from the correlated variable [52]. Some variables had VDPs above 0.5 in conjunction with the intercept, suggesting that the variable may have effectively been acting as a constant. As a result this variable was removed from the model. The remaining variables were assessed using backwards elimination checking for a greater than 10% change in the estimate and examining the changes in the confidence interval for increased precision.

Results

In the NHANES 2005-2006 database there were 10,438 total subjects with about half (n=5,369) under 20 years of age. Of these 532 subjects had missing values for the outcome, asthma, and 66 had missing values for the exposure, crowding (6 of these subjects had missing values for *both* crowding and asthma). Because some of the NHANES datasets only collect data on a subset of the population, additional variables had significant missings. After limiting to children and young adults and excluding those with missing values the final dataset included 4,777 subjects. Table 5 presents demographic characteristics of the subjects by asthma cases (n=479) and non-asthma controls (n=4,298).

Of the 4,777 subjects 2,538 (59%) controls were in the pre/primary school group with 277 (58%) of cases in this group. Of the 1,962 subjects who were teenagers 1,760 (41%) were controls and 202 (47%) were cases. These proportions were similar across cases and controls (chi-square=0.0841, p-value=0.8308). The subjects were 50% male with proportions of male and female subjects exhibiting comparable percentages between cases and controls (chi-square=5.9019, p-value=0.1016). For the race variables, while proportions for Non-Hispanic Whites (n=1,268, 27%) Other Hispanics (n=171, 4%) and Other race including multi-racial (n=269, 6%) were statistically similar across cases and controls, proportions for the categories Non-Hispanic Black (cases=1,299, 30%, controls=194, 45%, p-value=0.0063) and Mexican American (cases=1,467, 34%, controls=109, 25%, p-value=0.0031) differed between the two categories. One other personal characteristics variable examined was BMI, this was grouped as:

underweight (n=128, 3%), overweight (n=1,440, 30%), and normal weight (n=2,643, 55%). This variable had a number of missing values so that BMI information was only collected for 4,211 (88%) subjects. Poverty to income ratio was categorized as low (n=1,442, 30%), medium (n=2681, 55%), or high (n=1459, 30%).

Characteristics of housing thought to be associated with asthma are shown in Table 6. There were 1,439 (30%) detached homes in the final dataset with the remainder classified as attached. Age of home had a significant proportion of missing values with only 3,308 (70%) of total subjects reporting the year that their home was built. Of these 3,310 subjects, 936 (19%) subject-homes were built after 1959. Respondents also reported presence of cockroaches in the home (n=1144, 24%) and presence of mildew or musty smell in home (n=898, 19%). Presence of mildew/must was statistically different between cases and controls (chi-square=6.8462, p-value=0.0486).

Variables that were risk factors for asthma that may be related to crowding are shown in Table 7. The proportion of those suffering from a recent respiratory disease was significantly different (chi-square= 129.56, p-value=0<.0001) between cases (asthma sufferers) and controls (those without asthma) with 2,075 (48%) of controls reporting a recent infectious respiratory infection but 369 (85%) of the cases reporting a similar occurrence. There were 2,080 (44%) subjects who reported having had a pet in home currently or until recently. The variable indicating that the subject was a current smoker was missing for 58% of subjects, likely due to the fact that subjects were children. Only 251 (5%) of the subjects reported being a current smoker. Passive smoke exposure was indicated for 1,013 (21%) subjects. Additionally, 1,005 (21%) of subjects reported exposure to VOC producing substances, however, the proportion of persons reporting this between cases and controls was significantly different (chi-square= 13.522, p-value=0.0307). This meant that 891 (21%) controls reported these exposures and 114 cases (26%) also reported exposure to VOCs.

The crude OR of the relationship between crowding and asthma without controlling for any confounders is shown in Table 8. The multivariate model (Table 9) indicates a statistically significant association between crowding and asthma (OR 1.629, 95%CI: 1.054, 2517). After collinearity assessment and the use of backwards elimination the only two variables remaining in the model were those for age and home age. Collinearity assessment indicated that the variable for smoking should be dropped. The backwards elimination method compared the OR estimate and precision with the model containing all covariates (OR=1.664, 95%CI: 0.935, 2.959) (Table 10). While neither of the remaining variables showed a statistically significant association with the outcome these two variables remained in the model because removing them reduced the precision of the confidence interval.

Discussion

In this study asthma prevalence was found to be significantly associated with crowding after controlling for several important covariates, although the lower confidence interval was very close to the null value. Strengths of the study include the fact that NHANES is a large nationally representative sample of the population. The study collects detailed information on housing characteristics and respiratory outcomes with limited missing values. This allows for a thorough investigation of the association between the exposure and outcome, controlling for any intervening variables.

This study had several limitations, most notably the fact that asthma in the NHANES population is self-reported rather than medically diagnosed. This may lead to some subjects reporting that they have asthma when in fact the reverse is true. However, since outcomes and exposures for this study were chosen well after the interview point having the exposure was not likely to be correlated with self-reporting of asthma. Secondly, NHANES is a cross-sectional study which means that the results presented in this study have no time factor and are thus associations rather than causal relationships. Thirdly, because of low numbers of subjects in certain categories of confounders, data were often combined into larger categories, thus losing some information. Also, excluding persons with missing values could have led to selection bias in the study.

Importance for Future Health

Results suggest that a crowding level of greater than or equal to 0.71 was associated with increased prevalence of asthma in the NHANES 2005-2006 population of children and young adults. However, the OR of 1.629 was very different from the results found in similar studies, where crowding was found to be protective in the case of asthma [42, 43]. In those studies it was suggested that the hygiene hypothesis might be the reason for the protective association [42, 43]. In the current study, it is possible that increased dust produced from an excess of people living in the homes might irritate those with asthma increasing wheezing [22]. As discussed earlier, it is possible that allergens in dust may exacerbate or cause asthma [27, 28]. Additionally, crowding might cause increased contact with other irritants such as passive smoking [27].

Future Research

While crowding may not be overly present in countries such as the United States, low SES countries, and countries where land space is in short supply can suffer from an increased prevalence of crowding [53]. This may result in an increase in negative outcomes such as asthma, adverse mental health outcomes, and increased incidence of infectious diseases [17]. Future research with the NHANES data and crowding could perform sensitivity analyses for different methods of calculating density and different thresholds for crowding.

To summarize, crowding needs better guidelines that cover all of the possible definitions of density whether it be people per area of land, people per room, or square feet per person, since each of these methods relates to different health concerns [15]. Only by creating cutoff suggestions for each of the calculation methods can we hope to reduce the multitude of negative outcomes associated with crowding. Though crowding may function only as a proxy for other negative exposures such as passive smoking, increased contact with infectious persons, and lack of privacy it still appears to be a good predictor of asthma prevalence. In this study regulating number of people per rooms might have decreased the prevalence of asthma in the study population. Further studies are needed to evaluate the causality between crowding and asthma, and to examine whether the true relationship is one where crowding has a positive effect on asthma or whether crowding is associated with an increased number of asthma cases as was seen here.

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Tables and Figures

Tables

Table 1. Crowding Definitions. In studies that examined the effects of crowding on some outcome, or that used crowding as a covariate, the defintions used in the study appear below[1]

Density Definition	Threshold value	Reference Number[2]
No definition given		[32], [34]
Square feet of space per prisoner	None given	[14]
Number of people in subject's room	3 categories: ≤2, 3, ≥4 people in subjects room	[42]
Number of people per bedroom	None given	[2]
	4 categories: <3, 3-3.49, 3.5-4.99, ≥5 people per bedroom	[42]
	Continuous	[31]
Number of people per room (room undefined)	>1 people per room	[27], [35], [37]
	≤0.75 people per room	[40]
	≥5 people per room	[39]
	4 categories: <1, 1-1.49, 1.5-2.49, ≥2.5 people per room	[42]
	Continuous ?	[36]
Number of people per room (room=living rooms and bedrooms)	≥1.5 people per room	[43]
Number of children in household	Three comparison categories, 1 child per household (referent), 2 children per household, 3 or more children per household	[38]
	≤3	[41]
Shared household facilities	At least one shared facility	[33]
Families sharing a multi unit building	High-rise building >110 families	[10]
Urban crowding[3]	None given	[30]

[1] Studies that did not perform analysis but referenced the effects from crowding in another study do not appear in this table

[2] Studies may appear more than once if they assessed multiple methods of calculating crowding

[3] This study cites population density per hectare or per dwelling

Table 2. Datasets utilized from NHANES 2005-2006

SAS Data File	Data File Name
DEMO_D	Demographic Variables and Sample Weights
BMX_D	Body Measurements
VOC_D	Volatile Organic Compounds in Water and Related Questionnaire Items
AGQ_D	Allergy
HSQ_D	Current Health Status
ECQ_D	Early Childhood
HOQ_D	Housing Characteristics
MCQ_D	Medical Conditions
RDQ_D	Respiratory Disease
SMQ_D	Smoking – Cigarette Use
SMQRTU_D	Smoke – Recent Tobacco Use

Table 3. Continuous Crowding Variable. Basic Statistical Measures for Crowding in entire NHANES 2005-2006 population

Location		Variability	
Mean	0.71	**Std Deviation**	0.43
Median	0.63	**Variance**	0.18
Mode	1	**Range**	0.08, 7.00

Table 4. Variables in Dataset

Final variable	NHANES labels	NHANES variable(s) meanings	Creation Methodology	# of Levels	Cutpoints
Exposure					
Crowding	DMDHHSIZ	Number of people in household	DMDHHSIZ/HOQ050	2 levels	Mean of continuous crowding variable
	HOQ050	How many rooms are in this home, excluding bathrooms			
Outcome					
Asthma	MCQ010	Has a doctor or other health professional ever told {you/SP} that {you have/s/he/SP has} asthma?	If subject answered yes to both of these questions they were considered as having asthma	2 levels	Asthma (cases) / No asthma (controls)
	MCQ035	{Do you/Does SP} still have asthma?			
Covariates					
Age	RIDAGEYR	Best age in years of the sample person at time of HH screening. Individuals 85 and over are topcoded at 85 years of age.	Categorized into pre-school and primary school versus teen and college age	2 levels	0-12 years / 13-19 years
Gender	RIAGENDR	Gender of the sample person	Coded the same as NHANES	2 levels	Male / Female
Race/Ethnicity	RIDRETH1	Reported race or ethnicity	Coded the same as NHANES	5 levels	Non-Hispanic White / Non-Hispanic Black / Mexican American / Other Hispanic / Other Race - Including Multi Racial
Body mass index	RIDAGEMN	Best age in months at date of screening for individuals under 85 years of age.	Variables entered into CDC's SAS macro for children's BMI	3 levels	<5th percentile / ≥5th percentile but <85th percentile / ≥85th percentile
	RIAGENDR	Gender of the sample person			
	BMXHT	Standing Height (cm)			
	BMXWT	Weight (kg)			
	BMXHEAD	Head Circumference (cm)			
Poverty income ratio	INDFMPIR	Poverty income ratio (PIR) - a ratio of family income to poverty threshold	PIR was assigned 3 categories for poor, medium and high	3 levels	≤1 / >1 but less than 5 / ≥5
Attached Home	HOQ011	Is your home . . .{Mobile home or trailer / One family house detached / One family house attached / Apartment / Dormitory}?	Categorized into houses that are standalone residences and those they share walls, utilities, etc.	2 levels	Attached / Detached
Age of Home	HOQ040	When was this {mobile home/house/building} originally built?	Original 6 levels were dichotomized	2 levels	Before 1959 / 1960 or later
Presence of Cockroaches	HOQ240	In the past 12 months, have you seen any cockroaches in your home?	If subjects answered yes to this question they were considered to have cockroaches in their home	2 levels	Yes / No
Presence of Mold/Mildew	HOQ230	In the past 12 months, has your home had a mildew odor or musty smell?	If subjects answered yes to this question they were considered to have mold/mildew in their home	2 levels	Yes / No

Table 4. Variables in Dataset Con't

Final variable	NHANES labels	NHANES variable(s) meanings	Creation Methodology	# of Levels	Cutpoints
Covariates con't					
Current/Recent Respiratory Disease	AGQ010	Has a doctor or other health professional ever told {you/SP} that {you have/SP s/he has} hay fever?	If subject answered yes to any of these questions they were considered to have had a recent respiratory disease	2 levels	Yes / No
	AGQ040	Has a doctor or other health professional ever told {you/SP} that {you have/SP s/he has} allergies?			
	AGQ100	During the past 12 months, {have you/has SP} had a problem with sneezing, or a runny, or blocked nose when {you/s/he} did not have a cold or the flu?			
	AGQ120	During the past 12 months, did a doctor or other health professional tell {you/SP} that {you have/SP s/he has} a sinus infection?			
	HSQ500	Did {you/SP} have a head cold or chest cold that started during those 30 days?			
	HSQ520	Did {you/SP} have flu, pneumonia, or ear infections that started during those 30 days?			
Current/recent pet in home	HOQ250	Do any dogs, cats or other small furry animals, such as a rabbit, guinea pig or hamster, live or spend time in your home?	If subject answered yes to either of these questions they were considered to have had a pet in the home recently	2 levels	Yes / No
	HOQ270	In the last 12 months, did any dogs, cats or other small furry animals, such as a rabbit, guinea pig or hamster, live or spend time inside your home?			
Current smoking or tobacco	SMQ040	{Do you/Does SP} now smoke cigarettes . .	If subject answered yes to either of these questions they were considered to be a current smoker	2 levels	Yes / No
	SMQ680	During the past 5 days, did {you/he/she} use any product containing nicotine including cigarettes, pipes, cigars, chewing tobacco, snuff, nicotine patches, nicotine gum, or any other product containing nicotine?			
Exposure to passive smoking	VTQ260B	In the last three days, did you spend 10 or more minutes near a person who was smoking a cigarette, cigar, or pipe?	If subject answered yes to either of these questions they were considered to be passively exposed to smoking	2 levels	Yes / No
	SMD410	Does anyone who lives here smoke cigarettes, cigars, or pipes anywhere inside this home?			

Table 4. Variables in Dataset Con't

Final variable	NHANES labels	NHANES variable(s) meanings	Creation Methodology	# of Levels	Cutpoints
Covariates con't					
VOC exposure	VTQ280A	Breath fumes from paints?	If subject answered Yes to any of these questions they were considered to have had exposure to VOC fumes	2 levels	Yes / No
	VTQ280B	Breath fumes from degreasing cleaners?			
	VTQ280C	Breath fumes from diesel fuel or kerosene?			
	VTQ280D	Breath fumes from paint thinner, brush cleaner, or furniture stripper?			
	VTQ280E	Breath fumes from drycleaning fluid or spot remover?			
	VTQ280F	Breath fumes from fingernail polish or fingernail polish remover?			
	VTQ280G	Breath fumes from glues or adhesives used for hobbies or crafts?			

Table 5. Demographic and Personal Characteristics of Subjects that are associated with Asthma

Variables	Total Sample							
	Controls		Cases		Total			
	n=4,298	%	n=479	%	n=4,777	%	χ^2	p-value
Age								
0-12	2538	59%	277	58%	2,815	59%	0.0841	0.8308
13-19	1760	41%	202	47%	1,962	41%		
Gender								
Female	2195	51%	210	48%	2,405	50%	5.9019	0.1016
Male	2103	49%	269	62%	2,372	50%		
Race/Ethnicity								
Non-Hispanic White	1135	26%	133	31%	1,268	27%	2.4555	0.2427
Non-Hispanic Black	1299	30%	194	45%	1,493	31%	7.4771	0.0063
Mexican American	1467	34%	109	25%	1,576	33%	9.5868	0.0031
Other Hispanic	152	4%	19	4%	171	4%	0.334	0.635
Other Race - Including Multi-Racial	245	6%	24	6%	269	6%	9.4789	0.0732
BMI								
Underweight	120	3%	8	2%	128	3%	4.1227	0.0637
Normal Weight	2384	55%	259	60%	2,643	55%	3.726	0.2324
Overweight	1278	30%	162	37%	1,440	30%	7.7862	0.0946
Missing	516	12%	50	12%	566	12%		
PIR								
Low	1314	31%	128	30%	1,442	30%	1.2764	0.2849
Medium	2396	56%	283	65%	2,679	56%	0.8549	0.3152
High	407	9%	54	12%	461	10%	0.0005	0.9794
Missing	181	4%	14	3%	195	4%		

Table 6. Housing characteristics associated with Asthma

Variables	Total Sample							
	Controls		Cases		Total			
	n=4,298	%	n=479	%	n=4,777	%	χ^2	p-value
Home Type								
Detached	1295	30%	144	33%	1,439	30%	0.0317	0.8873
Attached	3003	70%	335	77%	3,338	70%		
Home Age								
Before 1959	839	20%	97	22%	936	20%	0.1029	0.7854
1960 to present	2125	49%	247	57%	2,372	50%		
Missing	1334	31%	135	31%	1,469	31%		
Mildew/Musty smell in home								
Yes	797	19%	101	23%	898	19%	6.8462	0.0486
No	3493	81%	378	87%	3,871	81%		
Seen Cockroaches								
Yes	1042	24%	102	24%	1,144	24%	5.3746	0.1808
No	3256	76%	377	87%	3,633	76%		

Table 7. Risk Factors for Asthma

Variables	Total Sample							
	Controls		Cases		Total			
	n=4,298	%	n=479	%	n=4,777	%	χ^2	p-value
Recent Respiratory Disease								
Yes	2075	48%	369	85%	2,444	51%	129.56	<.0001
No	1914	45%	100	23%	2,014	42%		
Missing	309	7%	10	2%	319	7%		
Pet in home currently/recently								
Yes	1843	43%	237	55%	2,080	44%	1.8578	0.4109
No	2447	57%	242	56%	2,689	56%		
Current Smoker								
Yes	227	5%	24	6%	251	5%	3.1759	0.2649
No	1553	36%	189	44%	1,742	36%		
Missing	2518	59%	266	61%	2,784	58%		
Passive Smoke in Home								
Yes	906	21%	107	25%	1,013	21%	0.5509	0.6312
No	3391	79%	372	86%	3,763	79%		
Exposed to VOC fumes								
Yes	891	21%	114	26%	1,005	21%	13.522	0.0307
No	3407	79%	365	84%	3,772	79%		

Table 8. Crude OR estimates for the effects of Crowding on Asthma

	Odds Ratio Estimates		
Effect	**Point Estimate**	**95% Wald Confidence**	
Non-crowded vs Crowded Home	1.375	1.06	1.788

Table 9. Logistic Regression Coefficients and OR estimates

Parameter	Point Estimate	95% Wald Confidence Limits		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept				1	-2.0479	0.3027	45.7551	<.0001
Crowding	1.629	1.054	2.517	1	0.4881	0.222	4.8334	0.0279
Age 13-20	0.703	0.427	1.159	1	-0.3518	0.2546	1.9092	0.1671
1960 to Present	0.955	0.571	1.596	1	-0.0465	0.2624	0.0315	0.8592

Table 10. Logistic regression Model with all suspected confounders

	Odds Ratio Estimates		
	Point	95% Wald	
Effect	**Estimate**	**Confidence Limits**	
Non-crowded vs Crowded Home	1.664	0.935	2.959
0-12	0.691	0.395	1.207
Gender	0.994	0.759	1.303
Black Non-Hispanic	1.004	0.677	1.487
Mexican American	0.824	0.54	1.259
Other Hispanic	0.435	0.136	1.392
Other Race	1.707	0.555	5.248
Low PIR	1.197	0.396	3.623
Mid PIR	1.172	0.667	2.059
Detached	0.844	0.39	1.829
Before 1960	0.954	0.617	1.474
Previous Respiratory disease	0.334	0.213	0.526
Current Smoker	0.561	0.269	1.168

Figures

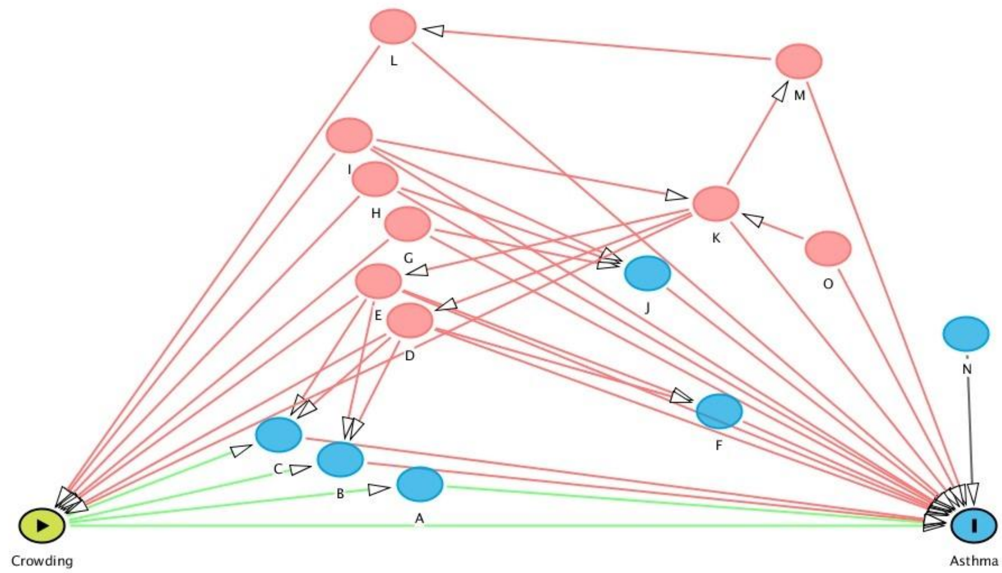

Figure 1. Directed Acyclic Graph for the relationship of Crowding on Asthma [50]

A=Passive Smoking
B=Fumes
C=Roaches
D=Attached Home
E=Home Age
F=Mildew
G=Race/Ethnicity
H=Age
I=Gender
J=BMI
K=PIR
L=Previous Respiratory Disease
M=Pet
N=Smoking

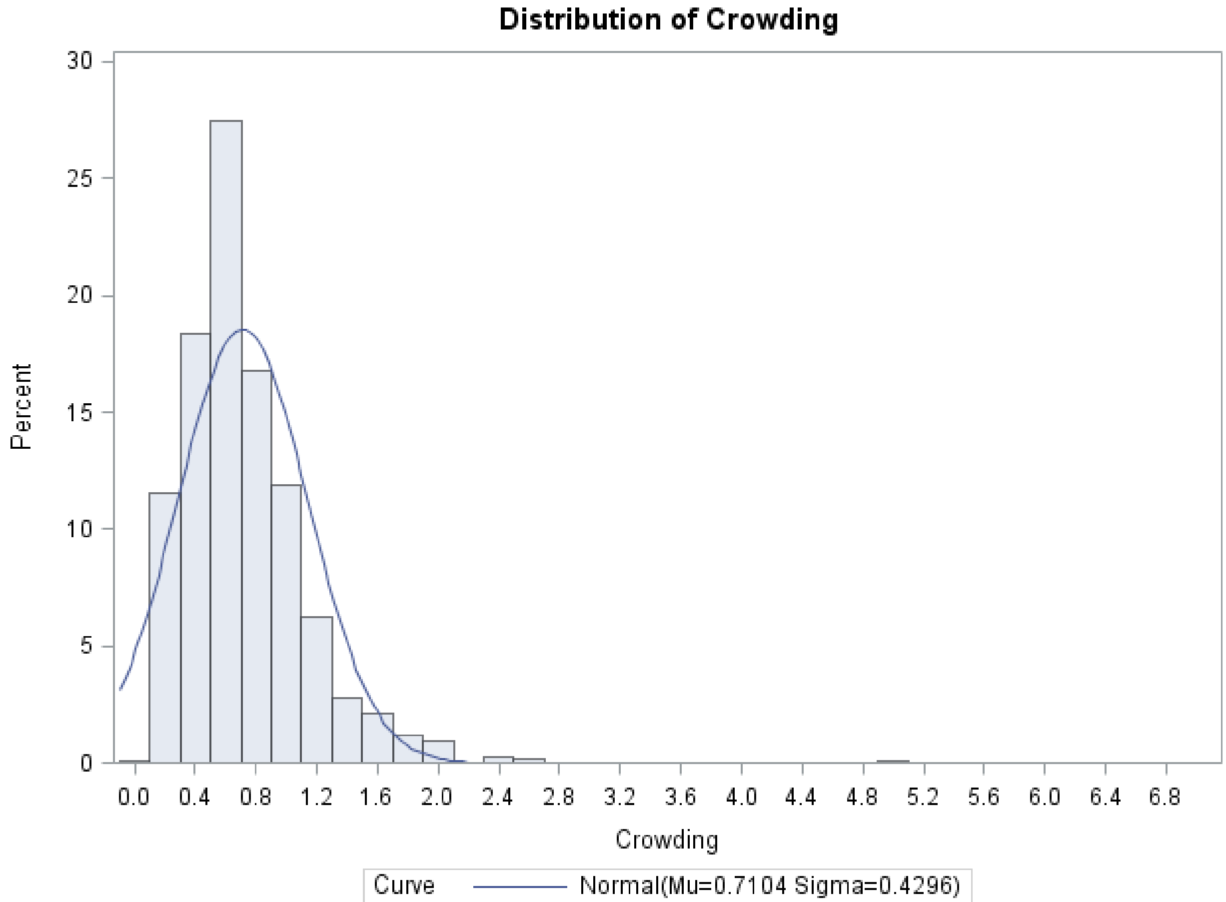

Figure 2. Histogram for the distribution of the crowding variable (SAS Institute, Cary, North Carolina)