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Neighborhood effects on obesity: a scoping review of longitudinal study designs

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NEIGHBORHOOD EFFECTS ON OBESITY: A SCOPING REVIEW OF LONGITUDINAL STUDY DESIGNS

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ABSTRACT

Introduction

Neighborhood effect research on obesity took off in the early 2000s, and was composed of mostly cross-sectional observational studies interested in various characteristics of the built environment and the socioeconomic environment. To limit biases related to self-selection and life course exposures, many researchers now apply longitudinal designs in their studies. Until now, no review has specifically and exclusively examined longitudinal studies or the specific designs of these studies. In this review, we intend to answer the following research question: How are the temporal measurements of contextual exposure and obesity outcomes integrated into longitudinal studies that explore how neighborhood-level built and socioeconomic environments impact adult obesity?

Methods and Analysis

A systematic search strategy was designed to address the research question, and to collect all possible publications relevant to this field from three scientific citation index databases. The eligible studies reported results on adults, included exposure that was limited to neighborhood characteristics at the sub-municipal level, included an outcome limited to obesity proxies (OP), and reported a design with at least two exposure measurements or two outcome measurements.

Discussion and Conclusion

This scoping review identified 66 studies that fit the eligibility criteria. A wide variety of neighborhood characteristics were also measured, making it difficult to draw general conclusions about associations between neighborhood exposure and obesity. We applied a typology that classified studies by whether exposure and outcome were measured as varying or fixed. Using this typology, we found that 32 studies reported both neighborhood exposure and obesity outcomes that were varying in time, 28 reported varying outcomes but fixed exposures, and six had fixed outcomes and varying exposures. This typology illustrates the variety of longitudinal designs that were used in the selected studies. In conclusion, we make recommendations on how to better report longitudinal designs and facilitate comparisons between studies.

ARTICLE SUMMARY

Strengths and limitations of this study:

- To our knowledge, this is the first review of longitudinal designs of neighborhood effect studies on obesity.
- This study proposes a typology to that classifies longitudinal studies by their design.
- The descriptive nature of a scoping review excludes quantitative analyses of the results.
- This scoping review excludes studies on children, which limits its scope but increases the homogeneity of the results.

1. BACKGROUND

Before the emergence of ecological models for weight change [1-3], obesity was mostly considered an individual responsibility. Efforts to combat the obesity epidemic were therefore focused on trying to influence the behaviors of individuals to either reduce their caloric intake or increase their caloric expenditure, or both. But such public health interventions did not have the expected results [4]. Worldwide, adult populations have shown increasing rates of obesity prevalence, although a slower rate has been observed in high-income countries [5, 6]. In children, trends in obesity prevalence have plateaued in high-income countries but are steadily increasing in East and South Asia [7].

Due to the mitigated success from the interventions that focused on individuals, some researchers expanded their focus by including the contextual factors in the causal web that may lead to obesity. Among the many levels of contextual factors, those related to neighborhoods quickly became aspects of interest for reasons both theoretical and practical. The observational theory that being overweight is heterogeneously geographically distributed on the neighborhood scale is a strong incentive for researchers to focus on the contextual influences that occur close to one's residence [8]. Also, the increase in obesity prevalence correlates over time with strong global contextual changes. A number of these changes include trade liberalization, economic growth and rapid urbanization, which impact the shape and dynamics of neighborhoods [9]. Among the more practical reasons for focusing on the neighborhood level is the hypothesis that the home environment is relatively easier to influence compared to the global food market or industrialization. Moreover, in some countries, local and national governments have the legislative and regulatory powers to plan neighborhoods. They are also responsible for health policies and services, which act as incentives for the government to lower health care costs and increase well-being by using contextual interventions.

Neighborhood effect research on obesity grew in popularity in the early 2000's [10], consisting of mostly cross-sectional observational studies. These studies were focused on various characteristics of the built environment (e.g. dwelling density, street connectivity, land use mix, food availability) and the socioeconomic environment (e.g. deprivation, safety, social cohesion) and their effect on different obesity proxies (OP) (e.g. BMI (Body Mass Index), weight, waist circumference). The last two decades saw the publication of a substantial number of such studies [10-19]. As of today, recent literature reviews specifically interested in the neighborhood level have identified urban sprawl (positively) and land use mix (negatively) to be associated with weight, only in North America [10] [14]. But authors have also reported methodological challenges, such as self-selection bias and the lack of life course exposure, and have suggested improving neighborhood effect studies by using longitudinal designs (i.e. using repeated measures of outcome and/or exposure) in order to move towards causality models [10, 14, 20].

Self-selection is a bias that can be introduced when individual residential localization choices are related to individual obesity outcomes [21, 22]. For instance, people who enjoy physical activity might prefer residential neighborhoods where many opportunities for such activities exist. People who enjoy traveling by car might prefer car-friendly neighborhoods compared to those who prefer walking [23]. These preferences and behaviors are often associated with obesity outcomes, but the time sequence between residential choice and weight gain cannot be disentangled in cross-sectional studies. In addition to the temporal sequence problem, cross-sectional studies have a limited capacity to examine the cumulative effect of neighborhood exposure on an individual [21, 24, 25]. An unhealthy obesity status can be the result of a very gradual weight gain. This potentially long latency combined with the effect of frequent residential moving is not captured by the current studies on neighborhood exposure [24, 26].

The ability of longitudinal studies to control for self-selection bias and life course exposure depends in part on their design; i.e. how outcome and exposure measurements are considered in time. Additionally, although some reviews of neighborhood effects on obesity did include a section dedicated to longitudinal studies, no review was specifically devoted to longitudinal studies or to the specific designs that were used.

2. RESEARCH QUESTION AND OBJECTIVES

This scoping review was specifically designed to answer the following research question: How are the temporal measurements of contextual exposure and obesity outcomes integrated into longitudinal studies that explore how neighborhood-level built and socioeconomic environments impact adult obesity?

To address this research question, the specific objectives of this review were to:

1. detail the number of studies investigating longitudinal neighborhood effects on obesity status and to describe their general characteristics;
2. describe and classify the study designs used to investigate longitudinal neighborhood effects on obesity status;
3. carry out a qualitative overview of the associations between neighborhood exposure and obesity status among studies that apply a longitudinal design.

3. MATERIALS AND METHODS

We decided to use a scoping review approach because the large number of study designs that were used in the literature makes it difficult and irrelevant to sum and compare results quantitatively [27]. Methods for this review are described in greater detail in the protocol [28]. A concise description of the methods is provided in the following sections.

3.1 Systematic search strategy

A systematic search strategy was designed to reflect the research question as closely as possible and to collect all possible studies relevant to this field of research while screening for the eligibility criteria described in Table 1.

Table 1 Eligibility criteria for selection of publications. Modified from the PICO (Population, Intervention, Comparison, Outcome) framework [27].

Criteria	***Description***
Population	*Eligible study populations were composed of adults between 18 and 65 years of age. At least two OPs and/or neighborhood characteristics must have been measured during adulthood (18 to 65 years old); other measurements may be collected in childhood, youth or older age.*
Exposure	*Exposure was measured by any indicator of neighborhood socioeconomic and/or built environment, where neighborhood is defined as an administratively delimited geographic area enclosing the participant's residence, a buffer-delimited area around the participant's residence, or a perceived area delimited by the participant. The geographic area must have been defined at the neighborhood level, which is smaller than a municipal area.*
Outcome	*The term "obesity" is generally used to refer to the accumulation of body fat and can be measured in numerous ways. Eligible studies were those reporting measured or self-reported OP such as total body weight, BMI, waist circumference, waist/hip ratio and/or skin fold thickness (with no specific thresholds). In this review, any study considering obesity status as an outcome was included.*
Study Design	*The studies must have included a longitudinal perspective in the measurement of the exposure and/or outcome. For example, studies applying the following designs were considered longitudinal: case-control studies and cohort studies, where exposure is measured at different points in time or classified as a pattern over time; or experimental or quasi-experimental schemes, where participants are exposed to different living environments over time. Cross-sectional and ecological studies were systematically excluded. Study designs that focused only on life course changes in obesity status without measuring contextual exposure were not included in this review.*

A search strategy was drafted by an experienced librarian (Frédérick Bergeron) and completed by the research team. The final search strategy involved identifying five keywords specifically related to the research question and articulated using Boolean operators:

Outcome terms AND longitudinal design terms AND (geographic context terms AND (social environment exposure terms OR physical environment exposure terms)).

This research strategy was modified to fit the search terms specific to three scientific citation index databases: *Embase, Web of Science* and *PubMed*. The full search strategy for PubMed is presented as an example in Supplementary file 1. Only peer-reviewed literature that was published in referenced journals in English were considered. The search was performed in February 2018 for scientific papers published before 01/01/2018.

3.2 Screening and Eligibility

The selection process was performed independently by two investigators (LL an SP). Kappa correlation was calculated to assess the inter-investigator agreement for selecting articles according to the title and abstract. Disagreements were resolved by attempting to reach a consensus between the two investigators. When a consensus could not be reached, a third observer (AL) was consulted to make a final decision. Most of the articles excluded at this point were ecological studies, studies with exposures measured at a scale other than the neighborhood, and studies with outcomes that were not obesity status. Pertinent articles from the reference list of included papers were also added to the screened records.

3.3 Charting

The charting process was conducted according to the steps described in the previously published protocol [28]. The construction of the chart also includes an iterative procedure of improvement, in order to consider other types of longitudinal designs that were not expected prior to the charting.

In its final form, the charting table contained the following information, extracted by one investigator (LL):

- Basic characteristics (year published, country of data collection, target population, type of outcome measure, exposure measure [type and neighborhood unit])
- Longitudinal characteristics (number of outcome measures, number of exposure measures, residential mobility of the population, change in neighborhood characteristics, typology of study designs)
- Direction and statistical significance of reported associations

Results were synthesized by grouping studies according to their basic and longitudinal characteristics and then summarizing their overall findings by analysing the reported associations.

4. RESULTS

4.1 Publication selection

Citations collected from the database searches were managed using Endnote X7.5. Duplicates were deleted. A flowchart of the selection process is presented in **Error! Reference source not found.**. From the 12,757 identified studies, after screening for relevant titles, abstracts and full manuscripts, 66 articles that fitted the eligibility criteria were selected [29-94]. Summary characteristics are shown in Table 2 and complete characteristics of the studies are shown in Supplementary file 2.

[Figure 1]

4.2 Basic characteristics

4.2.1 Year published

[Figure 2]

The selected studies were published over a relatively short time span, with the earliest publication in 2005 (**Error! Reference source not found.**). A general increasing pattern was observed, with a greater number of studies published each year. A particularly notable increase was observed for the last year of the review period (20 papers in 2017).

4.2.2 Countries of Origin

Among the selected articles, the studied populations were not particularly diverse. The majority of studies were from North America (79%, n= 52), and more specifically from the United States (74%, n=37). Of the non-American study populations, seven (11%) were European, two (3%) were from Asia and five (8%) were Australian.

4.2.3 Target Population

We focused on adult populations, who have more stable weight status patterns than children. Thus the selection criteria were set to include only studies in which two measurements were collected for OPs and/or neighborhood exposure during adulthood (18-65 years old). The majority of studies (n=33) examined non-specific adult populations. Six studies examined young adults (generally younger than 35 years old), while seven other studies were focused on older adults (generally older than 45 years old). Fourteen studies also chose specific sub-groups of the adult population that are susceptible to a differentiated neighborhood effect compared to the general adult population (women, African-American women, people with diabetes and migrants). Fourteen studies stratified their results for gender, four for race, and two for urban/rural places of residence.

4.2.4 Outcome Measures

The studies presented in this review were selected for outcomes associated with obesity. BMI was used as an outcome by 76% (n=50) of the studies, while waist circumference (or a ratio associated to waist and hip circumference) was used by 8% (n=5) of the studies. The remainder (17%, n=11) used weight or more than one type of measure as outcomes. Only one study included measurements of subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) [63].

Table 2 Distribution of the included studies, their overall findings and design characteristics

Characteristics	Included studies n	Included studies %	Null n	Mixed n	Expected n	Inverse n	% studies with expected findings
All	66	100%	34	6	25	1	38%
Outcome							
BMI	50	76%	24	5	20	1	40%
BMI and waist circumference	7	11%	6	1	.	.	.
Waist circumference	5	8%	2	.	3	.	60%
Weight	3	5%	2	.	1	.	33%
Adipose tissue volume	1	2%	.	.	1	.	100%
All	**66**	**100%**					
Type of attribute							
Built environment	32	49%	20	3	8	1	25%
Socioeconomic	30	46%	12	2	16	.	53%
Both	4	6%	2	1	1	.	25%
All	**66**	**100%**					
Geographic unit							
Census limits	25	38%	10	3	12	.	48%
Euclidean Buffer	13	20%	8	.	4	1	31%
Other	10	15%	8	1	1	.	10%
Administrative limits	9	14%	5	.	4	.	44%
Network buffer	7	11%	3	2	2	.	29%
Self-reported	2	3%	.	.	2	.	100%
All	**66**	**100%**					
Residential mobility							
Stayers and movers	46	70%	22	5	18	1	39%
Stayers	12	18%	7	.	5	.	42%
Stratified	6	9%	3	1	2	.	33%
Movers	2	3%	2	.	.	.	.
All	**66**	**100%**					
Change in neighborhood characteristics							
No	38	58%	16	3	19	.	50%
Yes	28	42%	18	3	6	1	21%
All	**66**	**100%**					
Typology							
Varying Outcome-Varying Exposure	32	49%	20	3	8	1	25%
Varying Outcome–Fixed Exposure	28	42%	12	3	13	.	46%
Fixed Outcome-Varying Exposure	6	9%	2	.	4	.	67%
All	**66**	**100%**					

4.2.5 Exposure Measurements

Each of the studies that were included was classified according to the primary exposure that was examined. About half the studies fell into the built environment category (49%, n=32) and slightly fewer fell into the socioeconomic indicators category (46%, n=30). A small proportion of studies included both types (6%, n=4). Table 3 shows all associations measured in all included studies (n=483) and groups them into indicator categories. Food environment indicators appeared most often (46%, n=223), followed by area deprivation (14%, n=66), green spaces (8%, n=40), socioeconomic composite index (7%, n=34), and perceived environment indicators (5%, n=25). The indicators used were widely varied in all the categories. For example, some food environment indicators focused on assessing healthy food environments, such as grocery store and supermarket densities [29, 62], and others focused on fast-food restaurant and convenience store densities [65, 90]. For composite indexes, authors applied an array of indexing methods, from preexisting indexes [50, 77, 84], to summing different indicators [42, 70, 80] or using principal component analyses [45, 54, 74, 75, 89, 95].

Table 3 Number of associations measured in selected studies and percent of statistically significant associations by indicator type

Indicator type	Associations N (% of all associations in study)		Statistically significant associations N (% by indicator type)	
Food environment	223	(46.2%)	53	(23.8%)
Deprivation	66	(13.7%)	18	(27.3%)
Green space	40	(8.3%)	8	(20.0%)
Composite index socioeconomic	34	(7.0%)	21	(61.8%)
Perceived environment	25	(5.2%)	4	(16.0%)
Security	25	(5.2%)	2	(8.0%)
Physical activity establishment	16	(3.3%)	4	(25.0%)
Walkability	11	(2.3%)	2	(18.2%)
Composite index built environment	10	(2.1%)	5	(50.0%)
Land use	9	(1.9%)	2	(22.2%)
Transportation infrastructure	6	(1.2%)	4	(66.7%)
Density	5	(1.0%)	2	(40.0%)
Racial composition	4	(0.8%)	2	(50.0%)
Distance to landmark	2	(0.4%)	2	(100.0%)
Other	2	(0.4%)	2	(100.0%)
Foreclosure	2	(0.4%)	1	(50.0%)
Sprawl	2	(0.4%)	0	(0.0%)
Prevalence of health behavior	1	(0.2%)	1	(100.0%)
All	**483**		**133**	

There was also a large amount of variability in the choice of neighborhood units that were used to calculate exposure. The neighborhood areas most often used were those defined by census limits (n=25, 38%), but quite a few studies relied on measurements such as Euclidean distance (n=13, 20%) or network distance (n=7, 11%), with a radius ranging from 100 m to 5 km around the individual's residence. Only two studies (2%) asked participants for a self-reported neighborhood area, and one study defined a neighborhood as a participant's activity space, including non-residential neighborhood exposure.

4.3 Longitudinal Characteristics

The included studies applied longitudinal designs, meaning that more than one measurement of neighborhood exposure or outcome in time was applied. Although all of the studies fit under the general definition of a longitudinal design, a few characteristics related to repeated measures and time allowed them to be categorized into subgroups.

4.3.1 Number of Outcome Measurements

There was wide variation in the number of outcomes measured among the selected studies. Six studies included only one outcome measurement, of which most were interventions or community trials. Thirty studies included two outcome measurements and 30 others included three or more different measurements. Among those, Laraia [62], who studied the impact of food environment on weight change in a population of patients who were clinically followed for diabetes, reported a median of 17 BMI measurements for the patients enrolled, with these measurements ranging from 10 to 27. This study reported the highest number of outcome measurements of all the studies selected for this review.

4.3.2 Number of Exposure Measurements

Neighborhood exposure measurements are more difficult to set in time than outcome measurements because they involve both the geographic location of the participants (generally in the form of an address, postal code or census area) and the contextual characteristics of their neighborhood (e.g. walkability, safety, greenness). Researchers can collect both pieces of information simultaneously or at different times. For example, Richardson [79] collected crime data from the city of Pittsburgh up to two years before the baseline year and also at the time of address collection from the participants in order to assess long term neighborhood exposure and its effect on BMI. Other studies did not simultaneously collect participant addresses and examine neighborhood characteristics simply because no neighborhood data were available at the baseline year. For example, Wasfi [88] linked the 2012 Walkscore data to address records from 1994-1995 since historical Walkscore data were available for that same period.

Studies including only one neighborhood exposure measurement were the most common (n=29), followed by studies including two measurements (n=17). The highest number of exposure assessments was reported by Murray and co-authors [71], who used a 20-year residential history questionnaire to assess the influence of poverty on BMI. They interpolated census-tract poverty for every month between three US censuses for every participant.

4.3.3 Residential Mobility

The residential mobility of participants is another characteristic related to time, as changes in residential location can contribute to changes in exposure to contexts. The vast majority (n=52, 79%) of the studies included both participants who still remained at the same residence at the time of the follow-up (stayers) and participants who had changed residences (movers). Six studies (9%) that included both stayers and movers in their sample presented a stratified analysis for residential mobility status. A few studies (n=12, 18%) included samples composed of participants who stayed in the same neighborhood for the entire duration of the follow-up period. Only two studies (3%) had samples composed of only people who moved during the follow-up period (movers).

4.3.4 Change in Neighborhood Characteristics

Another important characteristic linked to the longitudinal designs we examined is whether or not neighborhood context was considered a time-varying quantity. That is, regardless of whether or not participants changed their residential location, did the studies examine how the characteristics of the neighborhood changed over time? Less than half of the studies (n=28) considered the temporal changes in neighborhood context. There were several reasons that were provided for not measuring changes in neighborhood characteristics when two residential location measurements were collected. These reasons included the absence of historical data, such as the Walkscore® [39, 88], or the availability of data at only one time during the follow-up period, such as through a census or land survey [45, 56, 74, 75].

4.3.5 Typology of Study Designs

After examining the selected studies, we identified a three-category typology based on how outcomes and exposures were considered, related to time: time-varying outcome and fixed exposure studies (VO-FE), fixed outcome and time-varying exposure studies (FO-VE), and time-varying outcome and time-varying exposure studies (VO-VE).

In reality, both obesity and neighborhood exposures are time-varying. However, while planning a longitudinal study, the researchers considered their research questions and the data that were available in order to decide whether their statistical model should be based on fixed or time-varying outcomes and exposures. Outcomes and exposures were considered fixed when only one of these two measurements was collected. The outcome was considered time-varying when repeated measurements of OP were reported. The context was considered time-varying when either or both the geographical localization of participants and the neighborhood characteristics were repeatedly measured over time. The fixed outcome and fixed exposure design (FO-FE) was implicitly excluded from this review, since according to the eligibility criteria, no longitudinal studies applied this type of design.

Of the 28 studies using a VO-FE design (time-varying outcomes and fixed exposure), 18 only collected two measurements for the outcome using a typical baseline and follow-up design. Other studies used up to seven outcome measurements [44]. In general, the sole contextual measurement from these studies was synchronized with baseline outcome measurements, but Auchincloss [31] synchronized a contextual measurement with the third of four clinical assessments of BMI in order to measure the impact of perceived walkability and food environment [31].

The most prevalent type of design was the VO-VE type with time-varying outcomes and time-varying exposures, which included 32 studies. Of those, 27 had the same number of outcome and exposure measurements (either geographical localization or context characteristics). Hisrch [54], for example, used a US sample to measure BMI, waist circumference, geographical location and contextual characteristics at five points in time to examine the association between built environment and obesity. Twenty-four studies measured the characteristics of context and their changes over time while the others examined participant residential mobility to yield changes in exposure.

The FO-VE (fixed outcome and time-varying exposure) design was the least prevalent type of study. Six authors used this type of design, two of them in randomized social experiments from the Moving to Opportunity (MTO) study [42, 43] and two others were focused on neighborhood poverty trajectories [44, 45].

4.4 Qualitative Synthesis of Results

Although the objective of this review was mainly to examine longitudinal designs, a qualitative synthesis of the associations is presented to summarize the results obtained from the selected studies.

For each study, all associations were qualified based on statistical significance (at a level of 5%) and expected direction (as defined by the author). For studies using multiple models, results from the final and fully adjusted models were used. For articles measuring more than one association (n=46), an aggregated indicator was created to qualify the overall study findings, based on the criteria from two previous reviews [96, 97], and is presented in Table 4.

Table 4 Criteria used to define overall study findings based on the associations measured

Overall study findings	Statistical significance reported	Direction reported
Null	Less than 50% statistically significant associations	Inverse or expected
Mixed	50% statistically significant associations	Inverse or expected
Expected	More than 50% statistically significant associations	Expected
Inverse	More than 50% statistically significant associations	Inverse

Table 2 summarizes the overall findings of the reviewed studies according to their different characteristics. Of all the papers included in the review (n=66), 52% (n=34) reported a majority of non-significant associations and 39% (n=26) reported a majority of significant associations in the expected or inverse direction. The results were mixed for 9% of the papers, as they did not indicate a majority of significant, non-significant associations or inverse of the expected result.

When considering basic characteristics, studies that used waist circumference as an outcome measure, studies that measured socioeconomic neighborhood exposure and studies with fixed outcomes and varying exposure resulted in more than 50% of aggregated associations that were statistically significant in the expected direction. Categories with fewer than five studies were not considered for this analysis, as presented in Table 2.

Table 3 shows the results of the 483 disaggregated associations grouped by indicator type. Overall composite indexes of the socioeconomic environment and indicators of transportation infrastructure revealed more than 50% of the statistically significant associations, all in the expected direction. Groups of indicators with fewer than five associations were not considered for this analysis.

5. DISCUSSION

5.1 Main findings

5.1.1 Basic Characteristics

We conducted a systematic search of the scientific literature that examined associations between neighborhood characteristics and obesity outcomes and found 66 papers. These papers included some form of longitudinal design with repeated measures of outcome and/or repeated measures of exposure. Most of the papers that were selected for our review were published very recently. This rapid increase in the number of papers published in this area of research reflects a more general trend in studies about neighborhood effect on health as observed by Oakes [98], who in 2005, also revealed a substantial increase in such publications. However, this trend may also be due to the overall accelerated pace of publications that has been observed across most scientific domains [99].

There have been many calls to improve the research on neighborhood effect on health over the last 20 years [10, 17, 20, 22, 98, 100]. In addition to the longitudinal designs, which were the main focus of this review, we found that the more common suggestions for design improvement (conducting more studies on population subgroups, using adequate OPs, better identifying and defining neighborhoods) were taken into account in at least a few of the studies among the 66 that were selected.

Ding and Gebel [20] suggested that conducting more studies focused on populations outside the United States and on population groups such as women and ethnic minorities is a potential way to improve overall neighborhood effect research. Although most studies used samples from WEIRD populations (Western, Educated, Industrialized, Rich and Democratic [101]), a few studies that were included in this review focused on specific groups defined by gender, race, age or immigration status.

We also found that most of the studies selected BMI as an OP. Some authors have suggested that BMI does not accurately reflect the distribution of fat mass throughout the body, a factor that is hypothesized to have a substantial impact on the risk of cardiovascular disease and insulin resistance [102]. The use of waist circumference measurements is recommended at the individual level [103, 104], but this information is rarely available at the population level.

The studies in this review used diverse indicators to describe contextual exposure. The large variety of indicators in these studies makes it difficult to compare studies and draw conclusions for each type of indicator. Mackenbach [10], in a review of studies examining the association between built environment and weight, made a similar observation for both cross-sectional and longitudinal studies. However, in our review, we observed that this was not the case for food environment and socioeconomic indexes. These two categories combined amounted to nearly half the associations measured in the selected studies. The popularity of food environment indicators suggests that research on diet-related behaviors attracts more interest among the scientific community than physical activity and its determinants [105]. This may be because food availability data can be more easily collected than data on opportunities to participate in physical activity. Or perhaps because researchers observe the synchronicity between the changes in global food systems and the onset of the obesity epidemic to be an indication that the food environment could be the main influence for global weight gain [106]. The long history of literature linking socioeconomic status and cardiovascular risk factors [98, 107, 108] and the availability of historical socioeconomic data in national censuses may have also motivated numerous researchers to examine socioeconomic indexes. When we looked specifically at the indicators examined in these two prevailing categories (food environment and socioeconomic indexes), there was a wide diversity of indicators within the categories that made it difficult to compare studies.

5.1.2 Longitudinal Characteristics

As the main focus of this review, we first summarized how exposures and outcomes were set in time by applying a typology comprising three categories according to the longitudinal nature of the exposures and the outcomes. Using this typology allowed us to identify two key points: what the studies measured and what biases they attempted to address.

Studies with fixed exposure and varying outcomes (FE-VO) are generally designed to control for selection bias. Recording participant OP at an initial baseline exam, follow-up, and sometimes in between, limits the possibility that OP differences between individuals were only due to their OP prior to starting the study. This is an important improvement from cross-sectional studies. Some studies in this review reported contrasting results between cross-sectional and longitudinal data. Albrecht et al. [29] observed associations between the baseline waist circumferences and neighborhood food resources. However, they found no associations when using the changes in waistline circumference. Lee et al. [63] observed inconsistent results for the cross-sectional and longitudinal associations between intersection density, food store density and green space and visceral adipose tissue.

Fixed outcome and varying exposure (FO-VE) studies are designed to examine life course changes in neighborhood exposure or changes in neighborhood characteristics. As early as 2001, Diez Roux [22] recognized the importance of examining "the cumulative or interacting effects of neighborhood environments measured at different times over the life course, the effects of duration of exposure to certain neighborhood conditions, the effects of changes over time in neighborhood characteristics, and the impact of moving from one neighborhood to another." Our review found that every aspect of the longitudinal neighborhood effect that was suggested by Diez Roux has been the focus of at least one of the selected studies.

The VO-VE design, which was applied in the largest number of studies in this review, controls both for selection bias and life course exposure. For example, Burdette et al. [42] examined both temporal sequencing and life course and showed using a growth curve model that in a population of adolescents from the United States, those who lived in more disadvantaged neighborhoods at the baseline gained weight at a faster rate than those from a less disadvantaged neighborhood. Leonard et al. [64] demonstrated that the conditions of neighborhood change was related to changes in weight only among those who did not move from their neighborhood, thus controlling for self-selection bias and life course changes in neighborhood exposure.

The "fixed-varying" typology highlights the numerous research questions in the selected studies. Some studies posed research questions with particularities beyond the scope of this review, such as mediating behaviors or individual characteristics. But we could list at least six research questions directly related to neighborhood effect on obesity with some degree of longitudinal variation:

- What is the effect of neighborhood characteristics on OP change?
- What is the effect of neighborhood characteristics on OP trajectory?
- What is the effect of neighborhood characteristics change on OP change?
- What is the effect of moving to another neighborhood on OP?
- What is the effect of neighborhood trajectory on OP?
- What is the effect of a neighborhood intervention on obesity?

Each one of these questions is pertinent and illustrates one particular aspect of obesity and neighborhood evolution. However, the longitudinal characteristics added even more variety to the diverse neighborhood indicators, neighborhood definitions and OPs previously described, which makes it more difficult to draw meaningful conclusions that may be helpful for intervention design.

5.1.3 Qualitative Synthesis of Results

Although this was not the main focus of our review, we found no strong evidence on neighborhood effects on obesity in the longitudinal studies. Only 25 studies (38%) yielded statistically significant results in the expected direction. However, this does not necessarily indicate that neighborhood context has no effect, but that the specific characteristics of the neighborhood and how they are measured is important.

In terms of contextual measures, we found that studies reporting socioeconomic indicators of context yielded the majority of significant associations whereas studies on the built environment yielded the majority of non-significant association (Table 2). This may be because contextual socioeconomic indicators do in fact have a stronger effect on obesity or that associations with socioeconomic indicators are biased by more closely correlated individual socioeconomic indicators that are difficult to control for. This adds to the general findings from literature reviews that these results are generally equivocal. Black and Macinko [17] observed that economic resources and physical activity features of the neighborhood are significantly associated with obesity, while the associations between income inequality and racial composition were mixed, and food availability associations were inconsistent. Leal and Chaix [109] Fireported associations that were remarkably to reasonably consistent in all four categories (sociodemographic environment, physical environment, services and social interaction). Mackenbach [10] reported mixed results for the physical environment.

When considering the obesity outcome measurement, our review shows that studies using waist circumference, although few in number, yielded more statistically significant associations than studies using only BMI. This could be explained by the fact that the distribution of fat may be differentially influenced by lifestyle choices induced by neighborhood characteristics (i.e. increase in muscular mass or decrease in visceral fat versus subcutaneous fat) [102, 110-112] or that the studies using waistline measurements could have characteristics (number of participants, follow-up length, measurement quality,…) which could be associated with more statistical associations in the expected direction.

Finally, the type of design, whether using fixed or varying outcomes and exposures, did not seem to influence the significance or the direction of the association between the neighborhood exposure and the obesity outcome. Studies with fixed outcomes and varying exposure (FO-VE) did yield more statistically significant results than other types of longitudinal designs, but no definitive conclusions can be drawn due to the small number of studies. More studies of this type could contribute to better knowledge about neighborhood effects on obesity, but authors of such studies should be aware that there is less control over self-selection bias when the follow-up period is short or the exposure is not randomized.

5.2 Strengths and Weaknesses

We reviewed studies that were selected through a comprehensive research strategy. We also included a few papers that were cited in relevant publications. The selection criteria were designed to focus on observational studies. In strictly following the search strategy, we included some experimental and trial studies that appeared in our search results [41, 47, 57, 67, 94]. However these results could not be considered as a comprehensive appreciation of experimental schemes, and could therefore be the topic of a review paper of their own [113].

A person's weight status can vary greatly over their life course, with some periods and determinants playing more critical roles in the potential development of obesity [25, 114]. Therefore, although some authors have suggested that neighborhood effects are stronger when considering trajectories that include childhood, we have decided to limit this scoping review to measuring obesity in adults [115], for uniformity. This restriction likely limited the number of eligible publications and reduced the number of longitudinal designs to examine, but it also reduced the heterogeneity among the selected studies and likely facilitated greater comparability among them, considering that OP cut-off values are different for adults and children. [116] .

We also chose to limit our review to studies that focused on residential neighborhoods, despite research showing that they are not the only source of contextual exposure in a population [100]. Accessibilty to GPS technologies have allowed a number of studies to examine activity-space and better account for the environmental exposure of individuals. This environmental exposure includes the daily mobility of participants who are exposed to neighborhoods around their home, around their workplace, or other destinations related to their activities. One study [58] in our review found that accounting for activity-space and the time spent in different neighborhoods does influence the impact on obesity risk. Extending neighborhood effect research beyond residential environments could help draw a more complete picture of how neighborhoods and obesity status interact in time and space.

5.3 Unanswered Questions

Better understanding longitudinal designs used in studies on neighborhood effect on obesity prompts questions that can not be answered in this review. The most obvious one would be whether quantitative analysis of the results of longitudinal studies can be applied. Restricting the reviews to a specific category of indicators, such as the food environment or socioeconomic index or a specific type of design, could possibly provide enough homogeneity to perform such analyses. This would facilitate a quality analysis among studies, which was not possible in this review. Appraising statistical models, the length of follow-up periods?, the number of measurements and population size would be helpful for not only selecting studies for a systematic review, but also for suggesting quality standards for future longitudinal studies.

5.4 Implications for Future Research

One of the biggest challenges in conducting this review was the general difficulty in identifying the longitudinal characteristics in the selected studies. This reflects the challenging task of identifying and reporting every aspect of a study that can be influenced by time, and the difficulty in connecting these longitudinal characteristics with a specific research question. One of the most obvious examples is the residential mobility status of a population. In some articles, a group's choice to move or to stay in the same location was made clear, and was sometimes even stated in the publication's title [62, 64, 94] or research question [75]. But other authors neglected to mention the mobility status of their population or gave very little information about this factor, making it difficult to interpret the study's results and their meaning. Similarly, some publications provided very few details about changes in neighborhood characteristics or the time that neighborhood characteristic measurements were collected. Therefore, we suggest that future studies on longitudinal characteristics of neighborhood effects should report the following items whenever possible:

- **Mobility status:** specify whether participants moved residential locations during the follow-up period, stayed in the same residential location or whether the sample contains both types of mobility statuses.
- **Time of residential location measurement**: Report time (date or wave) at which the residential neighborhood of participants was localized;
- **Time of neighborhood characteristics measurements**: Report time at which the data describing neighborhood characteristics were collected. Specify if neighborhood characteristics vary in time (multiple neighborhood characteristic measurements).

The availability of data describing exposures or outcomes is an important obstacle when conducting quality longitudinal studies. Acquiring access to repeated measures of BMI or waist circumference that are linked to high-quality retrospective neighborhood measurements is highly challenging outside large-scale initiatives. Even with access to this information, capturing measurements that are more representative of neighborhoods, such as the perceived neighborhood or activity space, is a challenging task. It is worth considering the use of new technologies such as GPS data from mobile phones, geo-located data from social media, satellite imaging [72] and administrative open data as they become more available to researchers [117, 118].

6. CONCLUSION

Our scoping review, aimed at characterizing the designs of longitudinal studies examining neighborhood effects on obesity, identified 66 studies that fit our eligibility criteria. Overall, these longitudinal study designs were mostly intended to control for self-selection bias, although a fair number of studies also took life course exposure into consideration. The studies were very diverse in terms of the questions asked, indicators used and designs proposed, which limited the potential for conducting quantitative reviews of the results. On the other hand, the populations that were studied lacked diversity, suggesting that future studies should expand their interest to those outside WEIRD (Western, Educated, Industrialized, Rich and Democratic) populations. Additionally, we have proposed improvements for reporting longitudinal characteristics that could help authors design future longitudinal studies.

The diversified longitudinal study designs examined in this review reveal the intricate pathways in which the neighborhood and obesity may interact with time. Identifying these pathways is indispensable in the discussion about causality. However, at this time, they also compound the overwhelming diversity of neighborhood effect designs, which is an issue that has been identified as potentially hindering researchers from uncovering information that may prove useful for clinical or urban practices.

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9. PATIENT AND PUBLIC INVOLVEMENT

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination of our research.

10. AUTHOR CONTRIBUTIONS

Laurence Letarte designed this study, acquired, analyzed and interpreted the data and wrote the article. Sonia Pomerleau participated in data acquisition and contributed important intellectual content to the article. André Tchernof and Laurent Biertho revised the article and contributed important intellectual content. Alexandre Lebel participated in the study design, data interpretation, and revised the article and contributed important intellectual content. Owen Waygood participated in the study design, revised the article and contributed important intellectual content.

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12. DATA AVAILABILITY STATEMENT

All data relevant to the study are included in the article or uploaded as supplementary information

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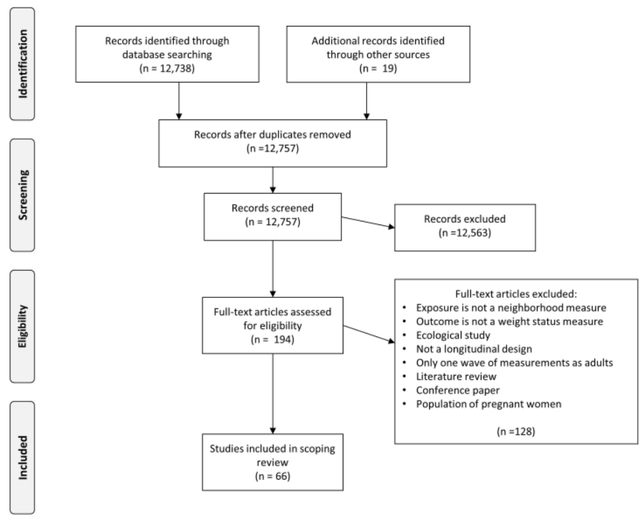
14.LEGENDS

Figure 1 Flowchart of the article selection process

Figure 2 Publication year of selected longitudinal studies of neighborhood effect on obesity

1



Flowchart of the article selection process

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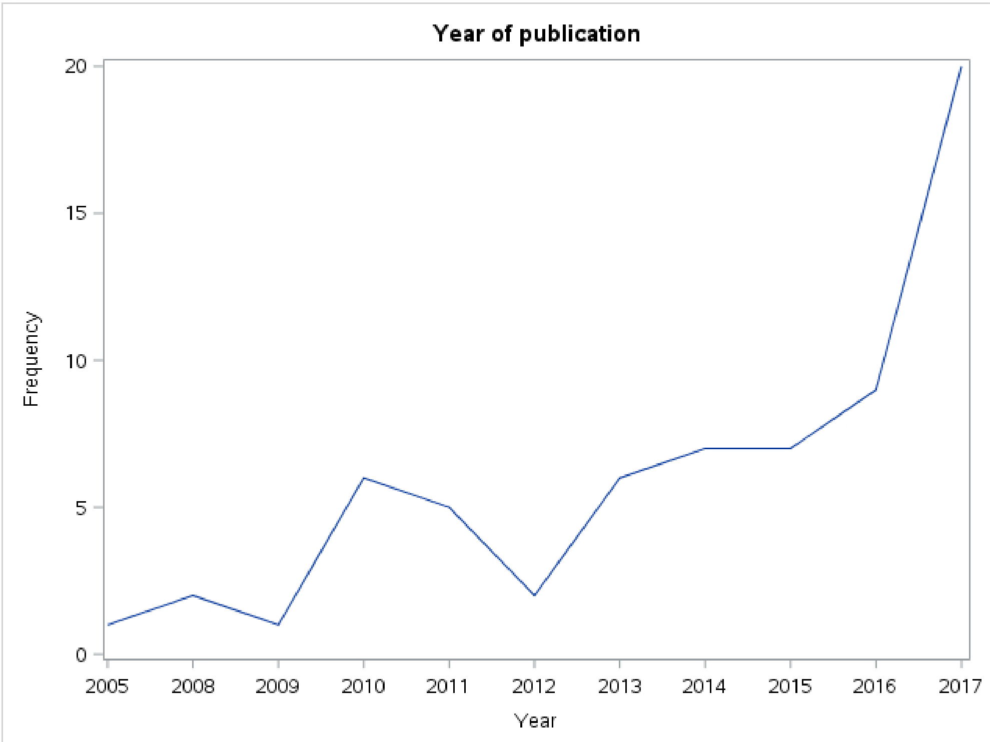

Publication year of selected longitudinal studies of neighborhood effect on obesity

SUPLEMENTARY FILE TABLE OF CONTENT

SUPPLEMENTARY FILE 1 : SAMPLE SEARCH STRATEGY

Outcome terms AND longitudinal design terms AND (geographic context terms AND (social environment exposure terms OR physical environment exposure terms))

Terms		Type*
Outcome		
1	Obesity	MeSH:noexp, TIAB
2	Obesity, Morbid	MeSH
3	Body Mass Index	MeSH, TIAB
4	BMI	TIAB
5	Overweight	MeSH:noexp, TIAB
6	Weight	TIAB
7	Adiposity	TIAB
Longitudinal design		
8	Cohort studies	MeSH
9	Prospective studies	MeSH
10	Cohort*	TIAB
11	Follow up	TIAB
12	Longitudinal	TIAB
13	Retrospective	TIAB
14	Life course	TIAB
15	Randomized	TIAB
16	Change	TIAB
17	Experimental	TIAB
18	History	TIAB
Geographic context		
19	Environment	MeSH:noexp
20	Residence characteristics	MeSH:noexp
21	Neighborhood*	TIAB
22	Neighbourhood*	TIAB
23	Catchment Area (Health)	MeSH
24	Residential	TIAB
25	Residence	TIAB
26	Context	TIAB
27	Composition	TIAB
28	Urban	TIAB
Social environment exposure		
29	Sociological Factors	MeSH:noexp, TIAB
30	Socioeconomic Factors	MeSH
31	Low-income	TIAB
32	Education	TIAB
33	Poverty	TIAB
34	Socioeconomic	TIAB
35	Income	TIAB
36	Social conditions	TIAB
Physical environment exposure		

37	Environment Design	MeSH
38	City Planning	MeSH, TIAB
39	Food service	MeSH
40	Urban planning	TIAB
41	Built Environment	TIAB
42	Physical environment	TIAB
43	Urban form	TIAB
44	Obesogenic environment	TIAB

**"Type" refers to the tags complementing search terms in queries. "MeSH" (Medical Subject Heading) terms will be searched in the controlled vocabulary assigned by U.S National Library of medicine to index scientific articles in its database. "MeSH:noexp" terms have the same function as MeSH, except that the search will be limited to the exact term not including subordinate terms generally linked to MeSH terms. "TIAB" terms will be searched in the title and abstract of the citations.*

SUPPLEMENTARY FILE 2 : CHARACTERISTICS OF SELECTED STUDIES

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Result (summary)	Statistically significant associations by indicator type
Albrecht, 2015 [1]	United States	Migrants	Waist circumference	Euclidean Buffer	1	5	Both	No	Null	Food environment 0/4 Walkability 0/2 Physical activity establishment 0/2
Arcaya, 2013 [2]	United States	Adults	BMI	Euclidean Buffer	3.8	3.8	Both	Yes	Expected	Foreclosure 1/1
Auchincloss, 2012 [3]	United States	Older adults	BMI	Self-reported	1	4	Both	No	Expected	À préciser
Auerbach, 2017 [4]	United States	African American women	BMI	Self-reported	1	2	Both	No	Expected	Physical activity establishment 1/1 Food environment 0/1 Security 1/1
Barrientos-Gutierrez, 2017 [5]	United States	Older adults	BMI	Euclidean Buffer	4	5	Both	Yes	Null	Food environment 0/2 Physical activity establishment 0/1 Walkability 0/1
Berry, 2010 [6]	Canada	Adults	BMI	Census limits	1	2	Both	No	Mixed	Composite index socioeconomic 1/1 Walkability 0/1
Berry, 2010 [7]	Canada	Adults	BMI	Administrative limits	1	2	Stayers	No	Null	Composite index socioeconomic 0/1 Walkability 0/1
Block, 2011 [8]	United States	Adults	BMI	Other	7	7	Both	Yes	Null	Food environment 5/36
Blok, 2013 [9]	Netherlands	Adults	BMI	Administrative limits	1	2	Both	No	Expected	Prevalence of health behavior 1/1
Boone-Heinonen, 2013 [10]	United States	Young adults	BMI	Euclidean Buffer	4	4	Both	Yes	Null	Food environment 1/3 Density 0/1 Deprivation 1/1 Physical activity establishment 0/2
Braun, 2016 [11]	United States	Older adults	Waist circumference	Other	2	2	Movers	No	Null	Walkability 0/1
Braun, 2016 [12]	United States	Young adults	BMI and waist ratio	Other	2	2	Movers	Yes	Null	Walkability 0/1

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Result (summary)	Statistically significant associations by indicator type
Brown, 2015 [13]	United States	Adults	BMI	Euclidean Buffer	2	2	Stayers	Yes	Expected	Transportation infrastructure 1/1
Burdette, 2012 [14]	United States	Young adults	BMI	Other	1	3	Both	No	Null	Composite index socioeconomic 1/1 Perceived environment 0/2
Christine, 2017 [15]	United States	Adults	BMI	Euclidean Buffer	2	2	Both	Yes	Null	Foreclosure 0/1
Colchero, 2008 [16]	Philippines	Women	BMI	Administrative limits	1	7	Both	No	Expected	Other 1/1 Density 1/1
Coogan, 2010 [17]	United States	African american women	BMI	Administrative limits	6	6	Both	No	Expected	Composite socioeconomic index 2/2
Coogan, 2011 [18]	United States	African american women	BMI	Network buffer	3	4	Both	No	Expected	Composite index built environment 2/2
Cummins, 2014 [19]	United States	Adults	BMI	Administrative limits	2	2	Stayers	Yes	Null	Food environment 0/1
Do, 2017 [20]	United States	Adults	BMI	Administrative limits	6	6	Both	Yes	Null	Deprivation 4/32
Eid, 2008 [21]	United States	Young adults	BMI	Euclidean Buffer	4.1	4.1	Both	No	Null	Sprawl 0/2 Mixed use 0/2
Feng, 2015 [22]	Australia	Adults	BMI	Census limits	1	2.9	Stayers	No	Expected	Composite index socioeconomic 1/1
Gebel, 2011 [23]	Australia	Adults	BMI	Other	1	2	Stayers	No	Expected	Perceived environment 1/1
Gibson, 2011 [24]	United States	Adults	BMI	Administrative limits	3.3	3.3	Both	Yes	Null	Food environment 4/10
Halonen, 2014 [25]	Finland	Profession	BMI	Other	2	2	Stratified	No	Null	Blue and green area 3/8
Hirsch, 2014 [26]	United States	Older adults	BMI and waist ratio	Euclidean Buffer	5	5	Both	Yes	Null	Composite built environment 2/6
Jones, 2014 [27]	United States	Adults	BMI and waist ratio	Census limits	1	2	Both	No	Mixed	Composite index socioeconomic 1/2
Joost, 2016 [28]	Switzerland	Adults	BMI	Census limits	2	2	Both	No	Expected	Deprivation 1/1

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Result (summary)	Statistically significant associations by indicator type
Kapinos, 2014 [29]	United States	Students	BMI	Other	1	2	Both	No	Null	Food environment ¼ Physical activity establishment 2/2
Kimbro, 2017 [30]	United States	Adults	BMI	Census limits	2	2	Both	Yes	Null	Deprivation 0/2 Food environment 0/6
Kwarteng, 2017 [31]	United States	Adults	Waist circumference	Census limits	1	2	Both	No	Expected	Deprivation 1/1
Kwarteng, 2016 [32]	United States	Adults	Waist circumference	Census limits	1	2	Both	No	Expected	Deprivation 1/1
Lamb, 2017 [33]	Australia	Women	BMI	Network buffer	2	3	Stayers	Yes	Null	Food environment 0/1
Laraia, 2017[34]	United States	Diabetes	BMI	Census limits	5	17	Stratified	Yes	Mixed	Food environment 2/4
Lee, 2017 [35]	United States	Adults	Other	Census limits	1	2	Both	No	Expected	Transportation 1/1 Greenspace 1/1 Inverse Land use 0/1 Food environment 5/5
Leonard, 2017 [36]	United States	Adults	BMI	Euclidean Buffer	2	2	Stratified	Yes	Expected	Composite index socioeconomic 3/3
Li, 2009 [37]	United States	Older adults	BMI and waist ratio	Census limits	1	2	Both	No	Null	Food environment 0/1 Walkability 0/1
Lippert, 2017 [38]	United States	Young adults	BMI and waist ratio	Census limits	2	1	Both	Yes	Null	Deprivation 3/12
Ludwig, 2011 [39]	United States	Women	BMI	Census limits	2	1	Both	No	Expected	Deprivation 1/1
Mendez, 2016 [40]	United States	Participants in weightloss program	Weight	Census limits	1	2	Both	No	Null	Food environment 0/2 Racial composition 1/1 Deprivation 0/4
Meyer, 2015 [41]	United States	Adults	BMI	Network buffer	4	4	Both	Yes	Mixed	Composite index built environment 1/2
Mujahid, 2005 [42]	United States	Older adults	BMI	Census limits	1	4	Both	No	Null	Composite index socioeconomic 0/4
Murray, 2010 [43]	United States	Older adults	BMI	Census limits	20	1	Both	Yes	Expected	Deprivation 1/1
Picavet, 2016 [44]	Netherlands	Adults	BMI	Euclidean Buffer	4	4	Both	Yes	Inverse	Green space 0/30

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Result (summary)	Statistically significant associations by indicator type
Pitts, 2017 [45]	United States	rural adults	Weight	Other	1	2	Both	No	Null	Food environment 1/10 Physical activity establishment 0/6 Walkability 0/1 Security 0/1 Perceived 0/1
Powell-Wiley, 2014 [46]	United States	Adults	Weight	Census limits	2	2	Stayers	No	Expected	Composite index socioeconomic 1/2
Powell-Wiley, 2015 [47]	United States	Adults	BMI	Census limits	2	2	Stratified	No	Expected	Composite index socioeconomic 3/3
Powell-Wiley, 2017 [48]	United States	Older adults	BMI and waist ratio	Other	5	5	Both	Yes	Null	Perceived environment 2/18 Security 0/18
Rachele, 2017 [49]	Australia	Older adults	BMI	Census limits	1	4	Stayers	No	Null	Composite index socioeconomic 0/2
Richardson, 2015 [50]	United States	Adults	BMI	Other	3	3	Both	Yes	Mixed	Food environment ½
Richardson, 2017 [51]	United States	African american	BMI	Euclidean Buffer	1	1	Both	Yes	Expected	Perceived environment 1/1 Security 1/1
Ruel, 2010 [52]	United States	Women	BMI	Census limits	1	4	Both	No	Null	Composite index socioeconomic 0/1 Racial composition 0/1
Rummo, 2017 [53]	United States	Adults	BMI	Network buffer	6	6	Both	Yes	Null	Food environment 2/7
Sarkar, 2013 [54]	United Kingdom	Older adults	BMI	Network buffer	1	3	Both	No	Mixed	Land use 2/6 Green space 0/1 Physical activity establishment 1/1 Transportation infrastructure 2/4 Other 1/1 Density 1/1
Sheehan, 2017 [55]	United States	Women	BMI	Census limits	2	1	Both	Yes	Expected	Deprivation 1/1
Stafford, 2010 [56]	United Kingdom	Profession	BMI	Census limits	1	3	Stratified	No	Null	Composite index socioeconomic ¼
Stoddard, 2013 [57]	United States	Patients with diabetes	BMI	Census limits	1	2	Both	No	Expected	Composite index socioeconomic 3/3
Sugiyama, 2016 [58]	Australia	Adults	Waist circumference	Network buffer	1	2	Stayers	No	Expected	Distance to landmark 2/2 Walkability 0/1
Sund, 2010 [59]	Norway	Adults	BMI	Census limits	1	2	Stayers	No	Null	Deprivation 0/1

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Result (summary)	Statistically significant associations by indicator type
Wasfi, 2016 [60]	Canada	Adults	BMI	Administrative limits	7	7	Both	No	Expected	Walkability 1/1
Xiao, 2017 [61]	United States	Older adults	BMI	Census limits	1	2	Both	No	Expected	Composite index socioeconomic 4/4
Xu, 2013 [62]	China	Adults	BMI and waist ratio	Administrative limits	4	4	Both	Yes	Null	Food environment 13/48
Zenk, 2017 [63]	United States	Adults	BMI	Euclidean Buffer	2	2	Stayers	Yes	Null	Food environment 1/6
Zenk, 2017 [64]	United States	Veterans	BMI	Euclidean Buffer	6	6	Stratified	Yes	Null	Food environment 17/48
Zhang, 2016 [65]	United States	Diabetes	BMI	Network buffer	1	2	Stayers	Yes	Null	Food environment 0/1
Zhao, 2014 [66]	United States	Afircan-American and Hispanic women	BMI	Census limits	2	1	Both	No	Null	Food environment 0/20 Racial composition 0/2 Deprivation 4/8 Security 0/4 Density 0/2

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Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	Page 1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	Page 2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	Pages 4-5
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	Page 5
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	Page 5
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	Page 6
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	Page 7
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Supplementary file 1
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	Page 7
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	Page 7-8
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	Page 7
Critical appraisal of individual	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe	Page 20

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SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
sources of evidence§		the methods used and how this information was used in any data synthesis (if appropriate).	
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	Page 7
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	Page 8
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Supplementary file 2
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	Not done
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Supplementary file 2
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	Pages 9-16
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	Pages 16-19
Limitations	20	Discuss the limitations of the scoping review process.	Page 19
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	Page 21
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	Page 22

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.
* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.
† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).
‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.
§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

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Neighborhood effects on obesity: a scoping review of time-varying outcomes and exposures in longitudinal designs

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NEIGHBORHOOD EFFECTS ON OBESITY: A SCOPING REVIEW OF TIME-VARYING OUTCOMES AND EXPOSURES IN LONGITUDINAL DESIGNS

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Obesity, neighborhood effect, longitudinal design, scoping review

ABSTRACT

Context and objectives

Neighborhood effect research on obesity took off in the early 2000s, and was composed of mostly cross-sectional observational studies interested in various characteristics of the built environment and the socioeconomic environment. To limit biases related to self-selection and life course exposures, many researchers apply longitudinal designs in their studies. Until now, no review has specifically and exclusively examined longitudinal studies and the specific designs of these studies. In this review, we intend to answer the following research question: How are the temporal measurements of contextual exposure and obesity outcomes integrated into longitudinal studies that explore how neighborhood-level built and socioeconomic environments impact adult obesity?

Design

A systematic search strategy was designed to address the research question. The search was performed in *Embase, Web of Science* and *PubMed* targeting scientific papers published before 01/01/2018. The eligible studies reported results on adults, included exposure that was limited to neighborhood characteristics at the sub-municipal level, included an outcome limited to obesity proxies (OP), and reported a design with at least two exposure measurements or two outcome measurements.

Results

This scoping review identified 66 studies that fit the eligibility criteria. A wide variety of neighborhood characteristics were also measured, making it difficult to draw general conclusions about associations between neighborhood exposure and obesity. We applied a typology that classified studies by whether exposure and outcome were measured as varying or fixed. Using this typology, we found that 32 studies reported both neighborhood exposure and obesity outcomes that were varying in time, 28 reported varying outcomes but fixed exposures, and six had fixed outcomes and varying exposures.

Conclusions

Our typology illustrates the variety of longitudinal designs that were used in the selected studies. In the light of our results, we make recommendations on how to better report longitudinal designs and facilitate comparisons between studies.

ARTICLE SUMMARY

Strengths and limitations of this study:

- To our knowledge, this is the first scoping review focussing on the designs of longitudinal studies of neighborhood effect on obesity.
- This study proposes a typology to that classifies longitudinal studies by their design.
- The descriptive nature of a scoping review excludes quantitative analyses of the results.
- This scoping review excludes studies on children, which limits its scope but increases the homogeneity of the results.

1. BACKGROUND

Before the emergence of ecological models for weight change [1-3], obesity was mostly considered an individual responsibility. Efforts to combat the obesity epidemic were therefore focused on trying to influence the behaviors of individuals to either reduce their caloric intake or increase their caloric expenditure, or both. But such public health interventions did not have the expected results [4]. Worldwide, adult populations have shown increasing rates of obesity prevalence, although a slower rate has been observed in high-income countries [5, 6]. In children, trends in obesity prevalence have plateaued in high-income countries but are steadily increasing in East and South Asia [7].

Due to the mitigated success from the interventions that focused on individuals, some researchers expanded their focus by including the contextual factors in the causal web that may lead to obesity. Among the many levels of contextual factors, those related to neighborhoods quickly became aspects of interest for reasons both theoretical and practical. The observational theory that being overweight is heterogeneously geographically distributed on the neighborhood scale is a strong incentive for researchers to focus on the contextual influences that occur close to one's residence [8]. Also, the increase in obesity prevalence correlates over time with strong global contextual changes. A number of these changes include trade liberalization, economic growth and rapid urbanization, which impact the shape and dynamics of neighborhoods [9]. Among the more practical reasons for focusing on the neighborhood level is the hypothesis that the home environment is relatively easier to influence compared to the global food market or industrialization. Moreover, in some countries, local and national governments have the legislative and regulatory powers to plan neighborhoods. They are also responsible for health policies and services, which act as incentives for the government to lower health care costs and increase well-being by using contextual interventions.

Neighborhood effect research on obesity grew in popularity in the early 2000's [10], consisting of mostly cross-sectional observational studies. These studies were focused on various characteristics of the built environment (e.g. dwelling density, street connectivity, land use mix, food availability) and the socioeconomic environment (e.g. deprivation, safety, social cohesion) and their effect on different obesity proxies (OP) (e.g. BMI (Body Mass Index), weight, waist circumference). The last two decades saw the publication of a substantial number of such studies [10-19]. As of today, recent literature reviews specifically interested in the neighborhood level have identified urban sprawl (positively) and land use mix (negatively) to be associated with weight, only in North America [10] [14]. A very recent literature review of longitudinal studies on built environment and cardio-metabolic health also found strong evidence for the impact of walkability on obesity [20]. But authors have also reported methodological challenges, such as self-selection bias and the lack of life course exposure, and have suggested improving neighborhood effect studies by using longitudinal designs (i.e. using repeated measures of outcome and/or exposure) in order to move towards causality models [10, 14, 21].

Self-selection is a bias that can be introduced when individual residential localization choices are related to individual obesity outcomes [22, 23]. For instance, people who enjoy physical activity might prefer residential neighborhoods where many opportunities for such activities exist. People who enjoy traveling by car might prefer car-friendly neighborhoods compared to those who prefer walking [24]. These preferences and behaviors are often associated with obesity outcomes, but the time sequence between residential choice and weight gain cannot be disentangled in cross-sectional studies. In addition to the temporal sequence problem, cross-sectional studies have a limited capacity to examine the cumulative effect of neighborhood exposure on an individual [22, 25, 26]. An unhealthy obesity status can be the result of a very gradual weight gain. This potentially long latency combined with the effect of frequent residential moving is not captured by the current studies on neighborhood exposure [25, 27].

The ability of longitudinal studies to control for self-selection bias and life course exposure depends in part on their design; i.e. how outcome and exposure measurements are considered in time. Additionally, although some reviews of neighborhood effects on obesity are interested in longitudinal studies, no review was specifically devoted to the specific designs that were used.

2. RESEARCH QUESTION AND OBJECTIVES

This scoping review was specifically designed to answer the following research question: How are the temporal measurements of contextual exposure and obesity outcomes integrated into longitudinal studies that explore how neighborhood-level built and socioeconomic environments impact adult obesity?

To address this research question, the specific objectives of this review were to:

1. detail the number of studies investigating longitudinal neighborhood effects on obesity status and to describe their general characteristics;
2. describe and classify the study designs used to investigate longitudinal neighborhood effects on obesity status;
3. carry out a qualitative overview of the associations between neighborhood exposure and obesity status among studies that apply a longitudinal design.

3. MATERIALS AND METHODS

We decided to use a scoping review approach because the large number of study designs that were used in the literature makes it difficult and irrelevant to sum and compare results quantitatively [28]. Methods for this review are described in greater detail in the protocol [29]. A concise description of the methods is provided in the following sections.

3.1 Systematic search strategy

A systematic search strategy was designed to reflect the research question as closely as possible and to collect all possible studies relevant to this field of research while screening for the eligibility criteria described in Table 1.

Table 1 Eligibility criteria for selection of publications. Modified from the PICO (Population, Intervention, Comparison, Outcome) framework [27].

Criteria	***Description***
Population	*Eligible study populations were composed of adults between 18 and 65 years of age. At least two OPs (obesity proxies) and/or neighborhood characteristics must have been measured during adulthood (18 to 65 years old); other measurements may be collected in childhood, youth or older age.*
Exposure	*Exposure was measured by any indicator of neighborhood socioeconomic and/or built environment, where neighborhood is defined as an administratively delimited geographic area enclosing the participant's residence, a buffer-delimited area around the participant's residence, or a perceived area delimited by the participant. The geographic area must have been defined at the neighborhood level, which is smaller than a municipal area.*
Outcome	*The term "obesity" is generally used to refer to the accumulation of body fat and can be measured in numerous ways. Eligible studies were those reporting measured or self-reported OP such as total body weight, BMI, waist circumference, waist/hip ratio and/or skin fold thickness (with no specific thresholds). In this review, any study considering obesity status as an outcome was included.*
Study Design	*The studies must have included a longitudinal perspective in the measurement of the exposure and/or outcome. For example, studies applying the following designs were considered longitudinal: case-control studies and cohort studies, where exposure is measured at different points in time or classified as a pattern over time; or experimental or quasi-experimental schemes, where participants are exposed to different living environments over time. Cross-sectional and ecological studies were systematically excluded. Study designs that focused only on life course changes in obesity status without measuring contextual exposure were not included in this review.*

147 A search strategy was drafted by an experienced librarian (Frédérick Bergeron) and completed by the research team. The final search strategy involved identifying five keywords specifically related to the research question and articulated using Boolean operators:

150 Outcome terms AND longitudinal design terms AND (geographic context terms AND (social environment exposure terms OR physical environment exposure terms)).

152 This research strategy was modified to fit the search terms specific to three scientific citation index databases: *Embase, Web of Science* and *PubMed*. The full search strategy for PubMed is presented as an example in Supplementary file 1. Only peer-reviewed literature that was published in referenced journals in English were considered. The search was performed in February 2018 for scientific papers published before 01/01/2018.

157 **3.2 Screening and Eligibility**

158 The selection process was performed independently by two investigators (LL an SP). Kappa correlation was calculated to assess the inter-investigator agreement for selecting articles according to the title and abstract. Disagreements were resolved by attempting to reach a consensus between the two investigators. When a consensus could not be reached, a third observer (AL) was consulted to make a final decision. Most of the articles excluded at this point were ecological studies, studies with exposures measured at a scale other than the neighborhood, and studies with outcomes that were not obesity status. Pertinent articles from the reference list of included papers were also added to the screened records.

166 **3.3 Charting**

167 The charting process was conducted according to the steps described in the previously published protocol [29]. The construction of the chart also includes an iterative procedure of improvement, in order to consider other types of longitudinal designs that were not expected prior to the charting.

170 In its final form, the charting table contained the following information, extracted by one investigator (LL):

172 - Basic characteristics (year published, country of data collection, target population, type of outcome measure, exposure measure [type and neighborhood unit])
174 - Longitudinal characteristics (number of outcome measures, number of exposure measures, residential mobility of the population, change in neighborhood characteristics, typology of study designs, statistical analysis)
177 - Direction and statistical significance of reported associations

Results were synthesized by grouping studies according to their basic and longitudinal characteristics and then summarizing their overall findings by analysing the reported associations.

3.4 Patient and Public Involvement

This research was done without patient involvement. Patients were not invited to comment on the study design and were not consulted to develop patient relevant outcomes or interpret the results. Patients were not invited to contribute to the writing or editing of this document for readability or accuracy

4. RESULTS

4.1 Publication selection

Citations collected from the database searches were managed using Endnote X7.5. Duplicates were deleted. A flowchart of the selection process is presented in Figure 1. From the 12,757 identified studies, after screening for relevant titles, abstracts and full manuscripts, 66 articles that fitted the eligibility criteria were selected [30-95]. Summary characteristics are shown in Table 2 and complete characteristics of the studies are shown in Supplementary file 2.

[Figure 1]

4.2 Basic characteristics

4.2.1 Year published

[Figure 2]

The selected studies were published over a relatively short time span, with the earliest publication in 2005 (Figure 2). A general increasing pattern was observed, with a greater number of studies published each year. A particularly notable increase was observed for the last year of the review period (20 papers in 2017).

4.2.2 Countries of Origin

Among the selected articles, the studied populations were not particularly diverse. The majority of studies were from North America (79%, n= 52), and more specifically from the United States (74%, n=37). Of the non-American study populations, seven (11%) were European, two (3%) were from Asia and five (8%) were Australian.

4.2.3 Target Population

We focused on adult populations, who have more stable weight status patterns than children. Thus, the selection criteria were set to include only studies in which two measurements were collected for OPs and/or neighborhood exposure during adulthood (18-65 years old). The majority of studies (n=33) examined non-specific adult populations. Six studies examined young adults (generally younger than 35 years old), while seven other studies were focused on older adults (generally older than 45 years old). Fourteen studies also chose specific subgroups of the adult population that are susceptible to a differentiated neighborhood effect compared to the general adult population (women, African-American women, people with diabetes and migrants). Fourteen studies stratified their results for gender, four for race, and two for urban/rural places of residence.

4.2.4 Outcome Measurements

The studies presented in this review were selected for outcomes associated with obesity. BMI was used as an outcome by 76% (n=50) of the studies, while waist circumference (or a ratio associated to waist and hip circumference) was used by 8% (n=5) of the studies (Table 2). 11% (n=7) used both BMI and waist circumference. One study included measurements of subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) [64].

Table 2 Distribution of the included studies, their overall findings and design characteristics

Characteristics	Included studies		Overall study findings				
			Null	Mixed	Expected	Inverse	% studies with
	n	%	n	n	n	n	expected findings
All	66	100%	28	15	22	1	33%
Outcome							
BMI	50	76%	18	13	18	1	36%
BMI and waist circumference	7	11%	6	1	.	.	.
Waist circumference	5	8%	2	.	3	.	60%
Weight	3	5%	2	1	.	.	.
Adipose tissue volume	1	2%	.	.	1	.	100%
All	**66**	**100%**					
Type of attribute							
Built environment	32	49%	15	10	6	1	19%
Socioeconomic	30	46%	11	4	15	.	50%
Both	4	6%	2	1	1	.	25%
All	**66**	**100%**					
Geographic unit							
Census limits	25	38%	9	5	11	.	44%
Euclidean Buffer	13	20%	6	2	4	1	31%
Other	10	15%	6	3	1	.	10%
Administrative limits	9	14%	4	1	4	.	44%
Network buffer	7	11%	3	2	2	.	29%
Self-reported	2	3%	.	2	.	.	.
All	**66**	**100%**					
Residential mobility							

Characteristics	Included studies		Overall study findings				
			Null	Mixed	Expected	Inverse	% studies with
	n	%	n	n	n	n	expected findings
Stayers and movers	46	70%	19	10	16	1	35%
Stayers	12	18%	6	2	4	.	33%
Stratified	6	9%	1	3	2	.	33%
Movers	2	3%	2	.	.	.	.
All	**66**	**100%**					
Change in neighborhood characteristics							
No	38	58%	13	9	16	.	42%
Yes	28	42%	15	6	6	1	21%
All	**66**	**100%**					
Typology							
Varying Outcome-Varying Exposure	32	49%	16	7	8	1	25%
Varying Outcome–Fixed Exposure	28	42%	10	8	10	.	36%
Fixed Outcome-Varying Exposure	6	9%	2	.	4	.	67%
All	**66**	**100%**					

4.2.5 Exposure Measurements

Each of the selected studies was classified according to the primary exposure that was examined. About half the studies fell into the built environment category (49%, n=32) and slightly fewer fell into the socioeconomic indicators category (46%, n=30). A small proportion of studies included both types (6%, n=4). Table 3 shows all associations measured in all included studies (n=483) and groups them into indicator categories. Food environment indicators appeared most often (46%, n=223), followed by area deprivation (14%, n=66), green spaces (8%, n=40), socioeconomic composite index (7%, n=34), and perceived environment indicators (5%, n=25). The indicators used were widely varied in all the categories. For example, some food environment indicators focused on assessing healthy food environments, such as grocery store and supermarket densities [30, 63], and others focused on fast-food restaurant and convenience store densities [66, 91]. For composite indexes, authors applied an array of indexing methods, from pre-existing indexes [51, 78, 85], to summing different indicators [43, 71, 81] or using principal component analyses [46, 55, 75, 76, 90, 96].

Table 3 Number of associations measured in selected studies and percent of statistically significant associations by indicator type

Indicator type	Associations N (% of all associations in study)	Statistically significant associations N (% by indicator type)
Food environment	223 (46.4%)	54 (24.2%)
Deprivation	66 (13.7%)	18 (27.3%)
Green space	40 (8.3%)	8 (20.0%)

Composite index socioeconomic	34	(7.0%)	21	(61.8%)
Security	25	(5.2%)	2	(8.0%)
Perceived environment	23	(4.8%)	4	(17.4%)
Physical activity establishment	15	(3.1%)	4	(26.7%)
Walkability	12	(2.5%)	1	(8.3%)
Composite index built environment	10	(2.1%)	5	(50.0%)
Land use	9	(1.9%)	2	(22.2%)
Transportation infrastructure	6	(1.3%)	4	(66.7%)
Density	5	(1.0%)	2	(40.0%)
Racial composition	4	(0.8%)	2	(50.0%)
Distance to landmark	2	(0.4%)	2	(100.0%)
Other	2	(0.4%)	2	(100.0%)
Foreclosure	2	(0.4%)	1	(50.0%)
Sprawl	2	(0.4%)	0	(0.0%)
Prevalence of health behavior	1	(0.2%)	1	(100.0%)
All	**481**		**133**	

There was also a large amount of variability in the choice of neighborhood units that were used to calculate exposure. The neighborhood areas most often used were those defined by census limits (n=25, 38%), but quite a few studies relied on measurements such as Euclidean distance (n=13, 20%) or network distance (n=7, 11%), with a radius ranging from 100 m to 5 km around the individual's residence. Only two studies (2%) asked participants for a self-reported neighborhood area, and one study defined a neighborhood as a participant's activity space, including non-residential neighborhood exposure.

4.3 Longitudinal Characteristics

The included studies applied longitudinal designs, meaning that more than one measurement of neighborhood exposure or outcome in time was applied. Although all of the studies fit under the general definition of a longitudinal design, a few characteristics related to repeated measures and time allowed them to be categorized into subgroups.

4.3.1 Number of Outcome Measurements

There was wide variation in the number of outcomes measured among the selected studies. Six studies included only one outcome measurement, of which most were interventions or community trials. Thirty studies included two outcome measurements and 30 others included three or more different measurements. Among those, Laraia [63], who studied the impact of food environment on weight change in a population of patients who were clinically followed for diabetes, reported a median of 17 BMI measurements for the patients enrolled, with these measurements ranging from 10 to 27. This study reported the highest number of outcome measurements of all the studies selected for this review.

4.3.2 Number of Exposure Measurements

Neighborhood exposure measurements are more difficult to set in time than outcome measurements because they involve both the geographic location of the participants (generally in the form of an address, postal code or census area) and the contextual characteristics of their neighborhood (e.g. walkability, safety, greenness). Researchers can collect both pieces of information simultaneously or at different times. For example, Richardson [80] collected crime data from the city of Pittsburgh up to two years before the baseline year and also at the time of address collection from the participants in order to assess long term neighborhood exposure and its effect on BMI. Other studies did not simultaneously collect participant addresses and examine neighborhood characteristics simply because no neighborhood data were available at the baseline year. For example, Wasfi [89] linked the 2012 Walkscore® data to address records from 1994-1995 since historical Walkscore® data were available for that same period.

Studies including only one neighborhood exposure measurement were the most common (n=29), followed by studies including two measurements (n=17). The highest number of exposure assessments was reported by Murray and co-authors [72], who used a 20-year residential history questionnaire to assess the influence of poverty on BMI. They interpolated census-tract poverty for every month between three US censuses for every participant.

4.3.3 Residential Mobility

The residential mobility of participants is another characteristic related to time, as changes in residential location can contribute to changes in exposure to contexts. The vast majority (n=52, 79%) of the studies included both participants who still remained at the same residence at the time of the follow-up (stayers) and participants who had changed residences (movers). Six studies (9%) that included both stayers and movers in their sample presented a stratified analysis for residential mobility status. A few studies (n=12, 18%) included samples composed of participants who stayed in the same neighborhood for the entire duration of the follow-up period. Only two studies (3%) had samples composed of only people who moved during the follow-up period (movers).

4.3.4 Change in Neighborhood Characteristics

Another important characteristic linked to the longitudinal designs we examined is whether or not neighborhood context was considered a time-varying quantity. That is, regardless of whether or not participants changed their residential location, did the studies examine how the characteristics of the neighborhood changed over time? Less than half of the studies (n=28) considered the temporal changes in neighborhood context. There were several reasons that were provided for not measuring changes in neighborhood characteristics when two residential location measurements were collected. These reasons included the absence of historical data, such as the Walkscore® [40, 89], or the availability of data at only one time during the follow-up period, such as through a census or land survey [46, 57, 75, 76].

4.3.5 Statistical analysis

Among the included publications, three main types of statistical analysis were applied to take into consideration the longitudinal structure of repeated measures. The most prevalent type of statistical analysis was multilevel model (n=28), which use a nested structure to allow within-individual random variation [97]. Multilevel models in included publications were composed of a combination of two to four levels, out of five possible levels (waves of the survey, individuals, family, neighborhoods, larger geographic area). The second most common statistical analysis type was the use of linear, logistic, or ordinal regression (n=13) to perform an analysis of change in a continuous, dichotomic, or ordinal OP. The third most frequent type of statistical analysis was fixed effect model(n=8), which use each individual as is own control to account for unmeasured time invariant characteristics. Two studies also used first-difference models similar to fixed effects models. The remaining studies used less common statistical strategies such as structural equations and spatial analysis or a combination of two types.

4.3.6 Typology of Study Designs

After examining the selected studies, we identified a three-category typology based on how outcomes and exposures were considered, related to time: time-varying outcome and fixed exposure studies (VO-FE), fixed outcome and time-varying exposure studies (FO-VE), and time-varying outcome and time-varying exposure studies (VO-VE).

In reality, both obesity and neighborhood exposures are time-varying. However, while planning a longitudinal study, the researchers considered their research questions and the data that were available in order to decide whether their statistical model should be based on fixed or time-varying outcomes and exposures. If only one measurement was collected for outcome or exposure then this part of the design was considered as fixed. The outcome was considered time-varying when repeated measurements of OP were reported. The context was considered time-varying when either or both the geographical localization of participants and the neighborhood characteristics were repeatedly measured over time. The fixed outcome and fixed exposure design (FO-FE) was implicitly excluded from this review, since according to the eligibility criteria, no longitudinal studies applied this type of design.

Of the 28 studies using a VO-FE design (time-varying outcomes and fixed exposure), 18 only collected two measurements for the outcome using a typical baseline and follow-up design. Other studies used up to seven outcome measurements [45]. In general, the sole contextual measurement from these studies was synchronized with baseline outcome measurements, but Auchincloss [31] synchronized a contextual measurement with the third of four clinical assessments of BMI in order to measure the impact of perceived walkability and food environment [32].

The most prevalent type of design was the VO-VE type with time-varying outcomes and time-varying exposures, which included 32 studies. Of those, 27 had the same number of outcome and exposure measurements (either geographical localization or context characteristics). Hisrch [55], for example, used a US sample to measure BMI, waist circumference, geographical location and contextual characteristics at five points in time to examine the association between built environment and obesity. Twenty-four studies measured the characteristics of context and their changes over time while the others examined participant residential mobility to yield changes in exposure.

The FO-VE (fixed outcome and time-varying exposure) design was the least prevalent type of study. Six authors used this type of design, two of them in randomized social experiments from the Moving to Opportunity (MTO) study [42, 43] and two others were focused on neighborhood poverty trajectories [44, 45].

4.4 Qualitative Synthesis of Results

Although the objective of this review was mainly to examine longitudinal designs, a qualitative synthesis of the associations is presented to summarize the results obtained from the selected studies.

For each study, all associations were qualified based on statistical significance (at a level of 5%) and expected direction (as defined by the author). For studies using multiple models, results from the final and fully adjusted models were used. For articles measuring more than one association (n=46), an aggregated indicator was created to qualify the overall study findings, based on the criteria from two previous reviews [98, 99], and is presented in Table 4.

Table 4 Criteria used to define overall study findings based on the associations measured

Overall study findings	Statistical significance reported	Direction reported
Null	0 %-33% statistically significant associations	Inverse or expected
Mixed	34%-59% statistically significant associations	Inverse or expected
Expected	More than 60% statistically significant associations	Expected
Inverse	More than 60% statistically significant associations	Inverse

Table 2 summarizes the overall findings of the reviewed studies according to their different characteristics. Of all the papers included in the review (n=66), 42% (n=28) reported a majority of non-significant associations and 33% (n=24) reported a majority of significant associations in the expected or inverse direction. The results were mixed for 23% of the papers, as they did not indicate a majority of significant, non-significant associations or inverse of the expected result.

When considering basic characteristics, studies that used waist circumference as an outcome measure, studies that measured socioeconomic neighborhood exposure and studies with fixed outcomes and varying exposure resulted in more than 60% of aggregated associations that were statistically significant in the expected direction. Categories with fewer than five studies were not considered for this analysis, as presented in Table 2.

Table 3 shows the results of the 481 disaggregated associations grouped by indicator type. Overall composite indexes of the socioeconomic environment and indicators of transportation infrastructure revealed more than 60% of the statistically significant associations, all in the expected direction. Groups of indicators with fewer than five associations were not considered for this analysis.

5. DISCUSSION

5.1 Main findings

5.1.1 Basic Characteristics

We conducted a systematic search of the scientific literature that examined associations between neighborhood characteristics and obesity outcomes and found 66 papers. These papers included some form of longitudinal design with repeated measures of outcome and/or repeated measures of exposure. Most of the papers that were selected for our review were published very recently. This rapid increase in the number of papers published in this area of research reflects a more general trend in studies about neighborhood effect on health as observed by Oakes [100], who in 2005, also revealed a substantial increase in such publications. However, this trend may also be due to the overall accelerated pace of publications that has been observed across most scientific domains [101].

There have been many calls to improve the research on neighborhood effect on health over the last 20 years [10, 17, 21, 23, 100, 102]. In addition to the longitudinal designs, which were the main focus of this review, we found that the more common suggestions for design improvement (conducting more studies on population subgroups, using adequate OPs, better identifying and defining neighborhoods) were taken into account in at least a few of the studies among the 66 that were selected.

Ding and Gebel [21] suggested that conducting more studies focused on populations outside the United States and on population groups such as women and ethnic minorities is a potential way to improve overall neighborhood effect research. Although most studies used samples from WEIRD populations (Western, Educated, Industrialized, Rich and Democratic [103]), a few of them focused on specific groups defined by gender, race, age or immigration status.

We also found that most of the studies selected BMI as an OP. Some authors have suggested that BMI does not accurately reflect the distribution of fat mass throughout the body, a factor that is hypothesized to have a substantial impact on the risk of cardiovascular disease and insulin resistance [104]. The use of waist circumference measurements is recommended at the individual level [105, 106], but this information is rarely available at the population level.

The studies in this review used diverse indicators to describe contextual exposure. The large variety of indicators in these studies makes it difficult to compare studies and draw conclusions for each type of indicator. Mackenbach [10], in a review of studies examining the association between the built environment and weight, made a similar observation for both cross-sectional and longitudinal studies. However, in our review, we observed that this was not the case for food environment and socioeconomic indexes. These two categories combined amounted to nearly half of the associations measured in the selected studies. The popularity of food environment indicators suggests that research on diet-related behaviors attracts more interest among the scientific community than physical activity and its determinants [107]. This may be because food availability data can be more easily collected than data on opportunities to participate in physical activity. Or perhaps because researchers observe the synchronicity between the changes in global food systems and the onset of the obesity epidemic to be an indication that the food environment could be the main influence for global weight gain [108]. The long history of literature linking socioeconomic status and cardiovascular risk factors [100, 109, 110] and the availability of historical socioeconomic data in national censuses may have also motivated numerous researchers to examine socioeconomic indexes. When we looked specifically at the indicators examined in these two prevailing categories (food environment and socioeconomic indexes), there was a wide diversity of indicators within the categories that made it difficult to compare studies.

5.1.2 Longitudinal Characteristics

As the main focus of this review, we first summarized how exposures and outcomes were set in time by applying a typology comprising three categories according to the longitudinal nature of the exposures and the outcomes. Using this typology allowed us to identify two key points: what the studies measured and what biases they attempted to address.

Studies with varying outcomes and fixed exposure (VO-FE) are generally designed to control for selection bias. Recording participant OP at an initial baseline exam, follow-up, and sometimes in between, limits the possibility that OP differences between individuals were only due to their OP prior to starting the study. This is an important improvement from cross-sectional studies. Some studies in this review reported contrasting results between cross-sectional and longitudinal data. Albrecht et al. [30] observed associations between the baseline waist circumferences and neighborhood food resources. However, they found no associations when using the changes in waistline circumference. Lee et al. [64] observed inconsistent results for the cross-sectional and longitudinal associations between intersection density, food store density and green space and visceral adipose tissue. Most studies with a VO-FE design used multilevel models to account for intra-individual variability.

Fixed outcome and varying exposure (FO-VE) studies are designed to examine life course changes in neighborhood exposure or changes in neighborhood characteristics. As early as 2001, Diez Roux [23] recognized the importance of examining "the cumulative or interacting effects of neighborhood environments measured at different times over the life course, the effects of duration of exposure to certain neighborhood conditions, the effects of changes over time in neighborhood characteristics, and the impact of moving from one neighborhood to another." Our review found that every aspect of the longitudinal neighborhood effect that was suggested by Diez Roux has been the focus of at least one of the selected studies. Most of the studies in this group used linear or logistic regression to estimate the effect of a change in the exposure or an exposure trajectory on an OP.

The VO-VE design, which was applied in the largest number of studies in this review, controls both for selection bias and life course exposure. For example, Burdette et al. [43] examined both temporal sequencing and life course and showed using a growth curve model that in a population of adolescents from the United States, those who lived in more disadvantaged neighborhoods at baseline gained weight at a faster rate than those from a less disadvantaged neighborhood. Leonard et al. [65] demonstrated that the conditions of neighborhood change was related to changes in weight only among those who did not move from their neighborhood, thus controlling for self-selection bias and life course changes in neighborhood exposure. As fixed effects models control for time invariant factors and require a change in exposure, all the studies using fixed effects models were found in this type of longitudinal designs. Multilevel models were also used to analyse VO-VE designs and a few studies [41, 44, 77, 89] presented results for both fixed effects and multilevel models. Some authors [31, 37, 59] also took advantage of multiple exposure measurements to build a cross-classified multilevel model where individuals were not nested in one neighborhood, but moved in time and were cross-classified into many neighborhoods.

The "fixed-varying" typology highlights the numerous research questions in the selected studies. Some studies posed research questions with particularities beyond the scope of this review, such as mediating behaviors or individual characteristics. But we could list at least six research questions directly related to neighborhood effect on obesity with some degree of longitudinal variation:

- What is the effect of neighborhood characteristics on OP change?
- What is the effect of neighborhood characteristics on OP trajectory?
- What is the effect of neighborhood characteristics change on OP change?
- What is the effect of moving to another neighborhood on OP?
- What is the effect of neighborhood trajectory on OP?
- What is the effect of a neighborhood intervention on obesity?

Each one of these questions is relevant and illustrates one particular aspect of obesity and neighborhood evolution. However, the longitudinal characteristics added even more variety to the diverse neighborhood indicators, neighborhood definitions and OPs previously described, which makes it more difficult to draw meaningful conclusions that may be helpful for intervention design.

5.1.3 Qualitative Synthesis of Results

Although this was not the main focus of our review, we found no strong evidence on neighborhood effects on obesity in the longitudinal studies. Only 25 studies (38%) yielded statistically significant results in the expected direction. However, this does not necessarily indicate that neighborhood context has no effect, but that the specific characteristics of the neighborhood and how they are measured is important.

In terms of contextual measurements, we found that studies reporting socioeconomic indicators of context yielded the majority of significant associations whereas studies on the built environment yielded the majority of non-significant association (Table 2). This may be because contextual socioeconomic indicators do in fact have a stronger effect on obesity or that associations with socioeconomic indicators are biased by more closely correlated individual socioeconomic indicators that are difficult to control for. This adds to the general findings from literature reviews that these results are generally equivocal. Black and Macinko [17] observed that economic resources and physical activity features of the neighborhood are significantly associated with obesity, while the associations between income inequality and racial composition were mixed, and food availability associations were inconsistent. Leal and Chaix [111] reported associations that were remarkably to reasonably consistent in all four categories (sociodemographic environment, physical environment, services and social interaction). Mackenbach [10] reported mixed results for the physical environment.

When considering the obesity outcome measurement, our review shows that studies using waist circumference, although few in number, yielded more statistically significant associations than studies using only BMI. This could be explained by the fact that the distribution of fat may be differentially influenced by lifestyle choices induced by neighborhood characteristics (i.e. increase in muscular mass or decrease in visceral fat versus subcutaneous fat) [104, 112-114] or that the studies using waistline measurements could have characteristics (number of participants, follow-up length, measurement quality,…) which could be associated with more statistical associations in the expected direction.

Finally, the type of design, whether using fixed or varying outcomes and exposures, did not seem to influence the significance or the direction of the association between the neighborhood exposure and the obesity outcome. Studies with fixed outcomes and varying exposure (FO-VE) did yield more statistically significant results than other types of longitudinal designs, but no definitive conclusions can be drawn due to the small number of studies. More studies of this type could contribute to better knowledge about neighborhood effects on obesity, but authors of such studies should be aware that there is less control over self-selection bias when the follow-up period is short or the exposure is not randomized.

5.2 Strengths and Weaknesses

We reviewed studies that were selected through a comprehensive research strategy. We also included a few papers that were cited in relevant publications. The selection criteria were designed to focus on observational studies. In strictly following the search strategy, we included some experimental and trial studies that appeared in our search results [42, 48, 58, 68, 95]. However, these results could not be considered as a comprehensive appreciation of experimental schemes, and could, therefore, be the topic of a review paper of their own [115].

A person's weight status can vary greatly over their life course, with some periods and determinants playing more critical roles in the potential development of obesity [26, 116]. Therefore, although some authors have suggested that neighborhood effects are stronger when considering trajectories that include childhood, we have decided to limit this scoping review to measuring obesity in adults [117], for uniformity. This restriction likely limited the number of eligible publications and reduced the number of longitudinal designs to examine, but it also reduced the heterogeneity among the selected studies and likely facilitated greater comparability among them, considering that OP cut-off values are different for adults and children. [118] .

We also chose to limit our review to studies that focused on residential neighborhoods, despite research showing that they are not the only source of contextual exposure in a population [102]. Accessibilty to GPS technologies have allowed a number of studies to examine activity-space and better account for the environmental exposure of individuals. This environmental exposure includes the daily mobility of participants who are exposed to neighborhoods around their home, around their workplace, or other destinations related to their activities. One study [59] in our review found that accounting for activity-space and the time spent in different neighborhoods does influence the impact on obesity risk. Extending neighborhood effect research beyond residential environments could help draw a more complete picture of how neighborhoods and obesity status interact in time and space.

5.3 Unanswered Questions

Better understanding longitudinal designs used in studies on neighborhood effect on obesity prompts questions that cannot be answered in this review. The most obvious one would be whether quantitative analysis of the results of longitudinal studies can be applied. Restricting the reviews to a specific category of indicators, such as the food environment or socioeconomic index or a specific type of design, could possibly provide enough homogeneity to perform such analyses. This would facilitate a quality analysis among studies, which was not possible in this review. Appraising statistical models, the length of follow-up periods, the number of measurements and population size would be helpful for not only selecting studies for a systematic review, but also for suggesting quality standards for future longitudinal studies.

5.4 Implications for Future Research

One of the biggest challenges in conducting this review was the general difficulty in identifying the longitudinal characteristics in the selected studies. This reflects the challenging task of identifying and reporting every aspect of a study that can be influenced by time, and the difficulty in connecting these longitudinal characteristics with a specific research question. One of the most obvious examples is the residential mobility status of a population. In some articles, a group's choice to move or to stay in the same location was made clear, and was sometimes even stated in the publication's title [63, 65, 95] or research question [76]. But other authors neglected to mention the mobility status of their population or gave very little information about this factor, making it difficult to interpret the study's results and their significance. Similarly, some publications provided very few details about changes in neighborhood characteristics or the time that neighborhood characteristic measurements were collected. Therefore, we suggest that future studies on longitudinal characteristics of neighborhood effects should report the following items whenever possible:

- **Mobility status:** specify whether participants moved residential locations during the follow-up period, stayed in the same residential location or whether the sample contains both types of mobility statuses.
- **Time of residential location measurement**: Report time (date or wave) at which the residential neighborhood of participants was localized;
- **Time of neighborhood characteristics measurements**: Report time at which the data describing neighborhood characteristics were collected. Specify if neighborhood characteristics vary in time (multiple neighborhood characteristic measurements).

The availability of data describing exposures or outcomes is an important obstacle when conducting quality longitudinal studies. Acquiring access to repeated measures of BMI or waist circumference that are linked to high-quality retrospective neighborhood measurements is highly challenging outside large-scale initiatives and especially outside WEIRD populations. Even with access to this information, capturing measurements that are more representative of neighborhoods, such as the perceived neighborhood or activity space, is a challenging task. It is worth considering the use of new technologies such as GPS data from mobile phones, geo-located data from social media, satellite imaging [73] and administrative open data as they become more available to researchers [119, 120].

6. CONCLUSION

Our scoping review, aimed at characterizing the designs of longitudinal studies examining neighborhood effects on obesity, identified 66 studies that fit our eligibility criteria. Overall, these longitudinal study designs were mostly intended to control for self-selection bias, although a fair number of studies also took life course exposure into consideration. The studies were very diverse in terms of the questions asked, indicators used and designs proposed, which limited the potential for conducting quantitative reviews of the results. On the other hand, the populations that were studied lacked diversity, suggesting that future studies should expand their interest to those outside WEIRD

(Western, Educated, Industrialized, Rich and Democratic) populations. Additionally, we have proposed improvements for reporting longitudinal characteristics that could help authors design future longitudinal studies.

The diversified longitudinal study designs examined in this review reveal the intricate pathways in which the neighborhood and obesity may interact with time. Identifying these pathways is indispensable in the discussion about causality. However, at this time, they also compound the overwhelming diversity of neighborhood effect designs, which is an issue that has been identified as potentially hindering researchers from uncovering information that may prove useful for clinical or urban practices.

7. DATA AVAILABILITY

All data relevant to the study are included in the article or uploaded as supplementary information.

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10.AUTHOR CONTRIBUTIONS

Laurence Letarte designed this study, acquired, analyzed and interpreted the data and wrote the article. Sonia Pomerleau participated in data acquisition and contributed important intellectual content to the article. André Tchernof and Laurent Biertho revised the article and contributed important intellectual content. Alexandre Lebel participated in the study design, data interpretation, and revised the article and contributed important intellectual content. Owen Waygood participated in the study design, revised the article and contributed important intellectual content.

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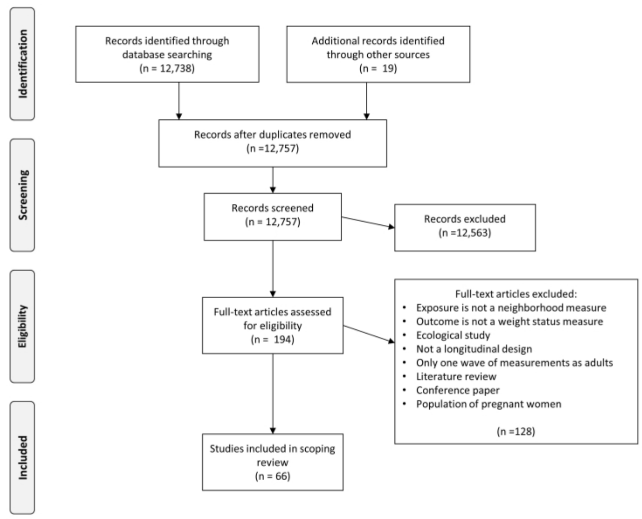
896 # 13.LEGENDS

897 Figure 1 Flowchart of the article selection process

898 Figure 2 Publication year of selected longitudinal studies of neighborhood effect on obesity

899



Flowchart of the article selection process

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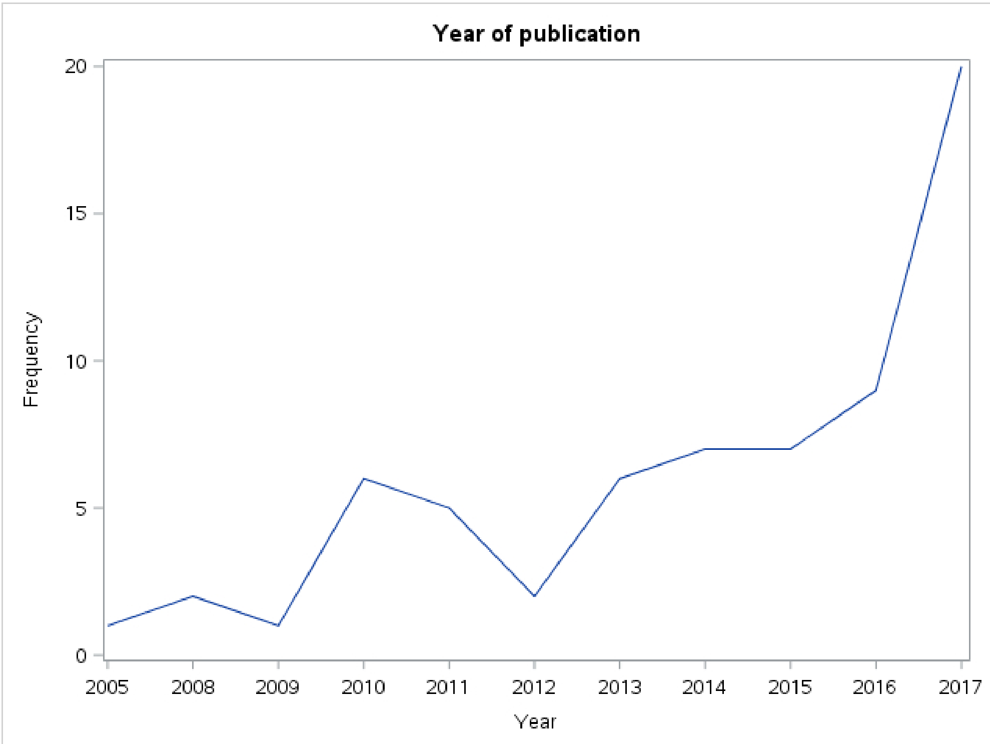

Publication year of selected longitudinal studies of neighborhood effect on obesity

SUPLEMENTARY FILE TABLE OF CONTENT

SUPPLEMENTARY FILE 1 : SAMPLE SEARCH STRATEGY

Outcome terms AND longitudinal design terms AND (geographic context terms AND (social environment exposure terms OR physical environment exposure terms))

Terms		Type*
Outcome		
1	Obesity	MeSH:noexp, TIAB
2	Obesity, Morbid	MeSH
3	Body Mass Index	MeSH, TIAB
4	BMI	TIAB
5	Overweight	MeSH:noexp, TIAB
6	Weight	TIAB
7	Adiposity	TIAB
Longitudinal design		
8	Cohort studies	MeSH
9	Prospective studies	MeSH
10	Cohort*	TIAB
11	Follow up	TIAB
12	Longitudinal	TIAB
13	Retrospective	TIAB
14	Life course	TIAB
15	Randomized	TIAB
16	Change	TIAB
17	Experimental	TIAB
18	History	TIAB
Geographic context		
19	Environment	MeSH:noexp
20	Residence characteristics	MeSH:noexp
21	Neighborhood*	TIAB
22	Neighbourhood*	TIAB
23	Catchment Area (Health)	MeSH
24	Residential	TIAB
25	Residence	TIAB
26	Context	TIAB
27	Composition	TIAB
28	Urban	TIAB
Social environment exposure		
29	Sociological Factors	MeSH:noexp, TIAB
30	Socioeconomic Factors	MeSH
31	Low-income	TIAB
32	Education	TIAB
33	Poverty	TIAB
34	Socioeconomic	TIAB
35	Income	TIAB
36	Social conditions	TIAB
Physical environment exposure		

37	Environment Design	MeSH
38	City Planning	MeSH, TIAB
39	Food service	MeSH
40	Urban planning	TIAB
41	Built Environment	TIAB
42	Physical environment	TIAB
43	Urban form	TIAB
44	Obesogenic environment	TIAB

*****"*Type" refers to the tags complementing search terms in queries. "MeSH" (Medical Subject Heading) terms will be searched in the controlled vocabulary assigned by U.S National Library of medicine to index scientific articles in its database. "MeSH:noexp" terms have the same function as MeSH, except that the search will be limited to the exact term not including subordinate terms generally linked to MeSH terms. "TIAB" terms will be searched in the title and abstract of the citations.*

SUPPLEMENTARY FILE 2 : CHARACTERISTICS OF SELECTED STUDIES

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Statistical analysis	Result (summary)	Statistically significant associations by indicator type
Albrecht, 2015 [1]	United States	Migrants	Waist circumference	Euclidean Buffer	1	5	Both	No	Multilevel model	Null	Food environment 0/4 Walkability 0/2 Physical activity establishment 0/2
Arcaya, 2013 [2]	United States	Adults	BMI	Euclidean Buffer	3.8	3.8	Both	Yes	Multilevel model	Expected	Foreclosure 1/1
Auchincloss, 2012 [3]	United States	Older adults	BMI	Self-reported	1	4	Both	No	Proportional hazards regression	Expected	Food environment 1/1 Walkability 0/1
Auerbach, 2017 [4]	United States	African American women	BMI	Self-reported	1	2	Both	No	Poisson regression analysis	Expected	Physical activity establishment 1/1 Food environment 0/1 Security 1/1
Barrientos-Gutierrez, 2017 [5]	United States	Older adults	BMI	Euclidean Buffer	4	5	Both	Yes	Fixed effects model	Null	Food environment 0/2 Physical activity establishment 0/1 Walkability 0/1
Berry, 2010 [6]	Canada	Adults	BMI	Census limits	1	2	Both	No	Linear regression	Mixed	Composite index socioeconomic 1/1 Walkability 0/1
Berry, 2010 [7]	Canada	Adults	BMI	Administrative limits	1	2	Stayers	No	Ordinal regression	Null	Composite index socioeconomic 0/1 Walkability 0/1
Block, 2011 [8]	United States	Adults	BMI	Other	7	7	Both	Yes	Multilevel model	Null	Food environment 5/36
Blok, 2013 [9]	Netherlands	Adults	BMI	Administrative limits	1	2	Both	No	Multilevel model	Expected	Prevalence of health behavior 1/1
Boone-Heinonen, 2013 [10]	United States	Young adults	BMI	Euclidean Buffer	4	4	Both	Yes	Fixed effects model	Null	Food environment 1/3 Density 0/1 Deprivation 1/1 Physical activity establishment 0/2

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Statistical analysis	Result (summary)	Statistically significant associations by indicator type
Braun, 2016 [11]	United States	Older adults	Waist circumference	Other	2	2	Movers	No	Fixed effects model	Null	Walkability 0/1
Braun, 2016 [12]	United States	Young adults	BMI and waist ratio	Other	2	2	Movers	Yes	Multiple	Null	Walkability 0/1
Brown, 2015 [13]	United States	Adults	BMI	Euclidean Buffer	2	2	Stayers	Yes	Linear regression	Expected	Transportation infrastructure 1/1
Burdette, 2012 [14]	United States	Young adults	BMI	Other	1	3	Both	No	Structural equations	Null	Composite index socioeconomic 1/1 Perceived environment 0/2
Christine, 2017 [15]	United States	Adults	BMI	Euclidean Buffer	2	2	Both	Yes	Multiple	Null	Foreclosure 0/1
Colchero, 2008 [16]	Philippines	Women	BMI	Administrative limits	1	7	Both	No	Multilevel model	Expected	Other 1/1 Density 1/1
Coogan, 2010 [17]	United States	African american women	BMI	Administrative limits	6	6	Both	No	Multilevel model	Expected	Composite socioeconomic index 2/2
Coogan, 2011 [18]	United States	African american women	BMI	Network buffer	3	4	Both	No	Multilevel model	Expected	Composite index built environment 2/2
Cummins, 2014 [19]	United States	Adults	BMI	Administrative limits	2	2	Stayers	Yes	Difference in difference	Null	Food environment 0/1
Do, 2017 [20]	United States	Adults	BMI	Administrative limits	6	6	Both	Yes	Multiple	Null	Deprivation 4/32
Eid, 2008 [21]	United States	Young adults	BMI	Euclidean Buffer	4.1	4.1	Both	No	First difference	Null	Sprawl 0/2 Land use 0/2
Feng, 2015 [22]	Australia	Adults	BMI	Census limits	1	2.9	Stayers	No	Multilevel model	Expected	Composite index socioeconomic 1/1
Gebel, 2011 [23]	Australia	Adults	BMI	Other	1	2	Stayers	No	Linear regression	Expected	Perceived environment 1/1
Gibson, 2011 [24]	United States	Adults	BMI	Administrative limits	3.3	3.3	Both	Yes	Fixed effects model	Mixed	Food environment 4/10

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Statistical analysis	Result (summary)	Statistically significant associations by indicator type
Halonen, 2014 [25]	Finland	Profession	BMI	Other	2	2	Stratified	No	Multilevel model	Mixed	Blue and green area 3/8
Hirsch, 2014 [26]	United States	Older adults	BMI and waist ratio	Euclidean Buffer	5	5	Both	Yes	Fixed effects model	Null	Composite built environment 2/6
Jones, 2014 [27]	United States	Adults	BMI and waist ratio	Census limits	1	2	Both	No	Multilevel model	Mixed	Composite index socioeconomic 1/2
Joost, 2016 [28]	Switzerland	Adults	BMI	Census limits	2	2	Both	No	Spatial analysis	Expected	Deprivation 1/1
Kapinos, 2014 [29]	United States	Students	BMI	Other	1	2	Both	No	Linear regression	Mixed	Food environment ¼ Physical activity establishment 2/2
Kimbro, 2017 [30]	United States	Adults	BMI	Census limits	2	2	Both	Yes	Multilevel model	Null	Deprivation 0/2 Food environment 0/6
Kwarteng, 2017 [31]	United States	Adults	Waist circumference	Census limits	1	2	Both	No	Multilevel model	Expected	Deprivation 1/1
Kwarteng, 2016 [32]	United States	Adults	Waist circumference	Census limits	1	2	Both	No	Multilevel model	Expected	Deprivation 1/1
Lamb, 2017 [33]	Australia	Women	BMI	Network buffer	2	3	Stayers	Yes	Multilevel model	Null	Food environment 0/1
Laraia, 2017[34]	United States	Diabetes	BMI	Census limits	5	17	Stratified	Yes	Fixed effects model	Mixed	Food environment 2/4
Lee, 2017 [35]	United States	Adults	Other	Census limits	1	2	Both	No	Linear and logistic regression	Expected	Transportation 1/1 Greenspace 1/1 Inverse Land use 0/1 Food environment 5/5
Leonard, 2017 [36]	United States	Adults	BMI	Euclidean Buffer	2	2	Stratified	Yes	Multilevel model	Expected	Composite index socioeconomic 3/3
Li, 2009 [37]	United States	Older adults	BMI and waist ratio	Census limits	1	2	Both	No	Multilevel model	Null	Food environment 0/1 Walkability 0/1
Lippert, 2017 [38]	United States	Young adults	BMI and waist ratio	Census limits	2	1	Both	Yes	Logistic regression	Null	Deprivation 3/12

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Statistical analysis	Result (summary)	Statistically significant associations by indicator type
Ludwig, 2011 [39]	United States	Women	BMI	Census limits	2	1	Both	No	Logistic regression	Expected	Deprivation 1/1
Mendez, 2016 [40]	United States	Participants in weightloss program	Weight	Census limits	1	2	Both	No	Fixed effects model	Null	Food environment 0/2 Racial composition 1/1 Deprivation 0/4
Meyer, 2015 [41]	United States	Adults	BMI	Network buffer	4	4	Both	Yes	Multilevel model	Mixed	Composite index built environment 1/2
Mujahid, 2005 [42]	United States	Older adults	BMI	Census limits	1	4	Both	No	Multilevel model	Null	Composite index socioeconomic 0/4
Murray, 2010 [43]	United States	Older adults	BMI	Census limits	20	1	Both	Yes	Linear regression	Expected	Deprivation 1/1
Picavet, 2016 [44]	Netherlands	Adults	BMI	Euclidean Buffer	4	4	Both	Yes	Multiple	Inverse	Green space 4/30
Pitts, 2017 [45]	United States	Rural adults	Weight	Other	1	2	Both	No	Linear regression	Null	Food environment 1/10 Physical activity establishment 0/6 Walkability 0/1 Security 0/1 Perceived 0/1
Powell-Wiley, 2014 [46]	United States	Adults	Weight	Census limits	2	2	Stayers	No	Multilevel model	Mixed	Composite index socioeconomic 1/2
Powell-Wiley, 2015 [47]	United States	Adults	BMI	Census limits	2	2	Stratified	No	Multilevel model	Expected	Composite index socioeconomic 3/3
Powell-Wiley, 2017 [48]	United States	Older adults	BMI and waist ratio	Other	5	5	Both	Yes	Multiple	Null	Perceived environment 2/18 Security 0/18
Rachele, 2017 [49]	Australia	Older adults	BMI	Census limits	1	4	Stayers	No	Multilevel model	Null	Composite index socioeconomic 0/2
Richardson, 2015 [50]	United States	Adults	BMI	Other	3	3	Both	Yes	Structural equation	Mixed	Food environment ½
Richardson, 2017 [51]	United States	African american	BMI	Euclidean Buffer	1	1	Both	Yes	Structural equation	Expected	Perceived environment 1/1 Security 1/1
Ruel, 2010 [52]	United States	Women	BMI	Census limits	1	4	Both	No	Multilevel model	Mixed	Composite index socioeconomic 0/1 Racial composition 1/1 Inverse

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Statistical analysis	Result (summary)	Statistically significant associations by indicator type
Rummo, 2017 [53]	United States	Adults	BMI	Network buffer	6	6	Both	Yes	Multiple	Null	Food environment 2/7
Sarkar, 2013 [54]	United Kingdom	Older adults	BMI	Network buffer	1	3	Both	No	Multilevel model	Mixed	Land use 2/6 Green space 0/1 Physical activity establishment 1/1 Transportation infrastructure 2/4 Other 1/1 Density 1/1
Sheehan, 2017 [55]	United States	Women	BMI	Census limits	2	1	Both	Yes	Logistic regression	Expected	Deprivation 1/1
Stafford, 2010 [56]	United Kingdom	Profession	BMI	Census limits	1	3	Stratified	No	Multilevel model	Null	Composite index socioeconomic ¼
Stoddard, 2013 [57]	United States	Patients with diabetes	BMI	Census limits	1	2	Both	No	Linear and logistic regression	Expected	Composite index socioeconomic 3/3
Sugiyama, 2016 [58]	Australia	Adults	Waist circumference	Network buffer	1	2	Stayers	No	Multilevel model	Expected	Distance to landmark 2/2 Walkability 0/1
Sund, 2010 [59]	Norway	Adults	BMI	Census limits	1	2	Stayers	No	Multilevel model	Null	Deprivation 0/1
Wasfi, 2016 [60]	Canada	Adults	BMI	Administrative limits	7	7	Both	No	Multiple	Expected	Walkability 1/1
Xiao, 2017 [61]	United States	Older adults	BMI	Census limits	1	2	Both	No	Logistic regression	Expected	Composite index socioeconomic 4/4
Xu, 2013 [62]	China	Adults	BMI and waist ratio	Administrative limits	4	4	Both	Yes	Multilevel model	Null	Food environment 13/48
Zenk, 2017 [63]	United States	Adults	BMI	Euclidean Buffer	2	2	Stayers	Yes	Multilevel model	Null	Food environment 1/6
Zenk, 2017 [64]	United States	Veterans	BMI	Euclidean Buffer	6	6	Stratified	Yes	Fixed effects model	Mixed	Food environment 17/48

Author, year of publication	Country	Target group	Outcome	Geographic unit	Number of contextual measures	Number of outcome measures	Residential mobility	Change in neighborhood characteristics	Statistical analysis	Result (summary)	Statistically significant associations by indicator type
Zhang, 2016 [65]	United States	Diabetes	BMI	Network buffer	1	2	Stayers	Yes	First difference	Null	Food environment 0/1
Zhao, 2014 [66]	United States	Africcan-American and Hispanic women	BMI	Census limits	2	1	Both	No	Linear regression	Null	Food environment 0/20 Racial composition 0/2 Deprivation 4/8 Security 0/4 Density 0/2

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Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	Page 1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	Page 2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	Pages 4-5
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	Page 5
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	Page 5
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	Page 6
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	Page 7
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Supplementary file 1
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	Page 7
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	Page 7-8
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	Page 7
Critical appraisal of individual	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe	Page 20

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SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
sources of evidence§		the methods used and how this information was used in any data synthesis (if appropriate).	
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	Page 7
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	Page 8
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Supplementary file 2
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	Not done
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Supplementary file 2
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	Pages 9-16
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	Pages 16-19
Limitations	20	Discuss the limitations of the scoping review process.	Page 19
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	Page 21
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	Page 22

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

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