BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-028238
Article Type:	Original research
Date Submitted by the Author:	28-Nov-2018
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Keywords:	PUBLIC HEALTH, Obesity, NUTRITION & DIETETICS

Neighborhood socioeconomic status and overweight/obesity: a systematic review and meta-analysis of epidemiological studies

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Word count: 3,320

Abstract

Objective: Poor neighborhood socioeconomic conditions have been linked to a higher risk of overweight/obesity, irrespective of individuals own socioeconomic status. However, there is no meta-analysis report is on the association. We aimed to synthesize the existing evidence and provide pooled estimates.

Method: We searched PubMed, EMBASE, SCOPUS, Web of Sciences and Google Scholar for studies on the association of neighborhood socioeconomic conditions with overweight or obesity, published from inception to June 15, 2018. The pooled estimates of the relationship of neighborhood socioeconomic status with overweight and obesity were calculated with random effects meta-analysis models. Heterogeneity between the studies was assessed by Cochran's Q and I^2-statistics. Subgroup analyses were done by age categories, continents, study designs, and

methods of neighborhood socioeconomic measures. Publication bias was assessed by visual inspection of funnel plots and Egger's regression test.

Result: A total of 10 studies, covering 1,151,409 individuals, were included in this meta-analysis. Residence in poor neighborhoods, compared with residence in better-off neighborhoods, was found associated with a 31% higher odds of overweight (pooled OR=1.31, 95%CI=1.16-1.47, P<0.001), and a 43% higher odds of obesity (pooled OR=1.43, 95%CI=1.18-1.74, P<0.001).

Conclusion: Neighborhood economic deprivation may be contributing to the burden of overweight/obesity. Further studies are warranted, including whether addressing neighborhood economic disparity reduces the risk of overweight/obesity.

PROSPERO Registration: CRD42017063889

Keywords: Neighborhood socioeconomic status, Obesogenic environment, Overweight, Obesity, Meta-analysis

Strengths and limitations

- This is the first meta-analysis study on the association of neighborhood socioeconomic status with overweight/obesity.
- The studies included are observational in design, precluding making causal inference.
- There is heterogeneity in the methods of measuring neighborhood socioeconomic status.
- The studies are mainly based on western population, limiting the generalizability of the findings to other setups.

Introduction

Obesity remains a major global public health problem. While the current level of obesity already poses a significant burden to the health system, the problem is still on the rise and causing more negative consequences at both individual and society levels.[1] Worldwide, 39% of adults were estimated to be overweight in 2016. In the same year, 13% of adults were estimated to be obese; almost triple of the figure in 1975.[1] The World Health Organization (WHO) has prioritized the prevention and control of obesity as a central public health agenda and recommends nations to make a substantial improvement with regard to the current trend of obesity.[2] However, the global progress to curb the rise and burden of overweight/obesity has been slow and frustrating, with each consecutive generation developing overweight/obesity at an early age and at higher rates.[3] [4]

Overweight/obesity is a multi-causal problem, with its influences originating from various levels; including individual, social, and environmental origins. According to ecological models of obesity causation, the risk factors of overweight/obesity often interact with each other and may be of direct or indirect influences on the weight status of individuals.[5-7] The main direct determinants are often

unhealthy dietary patterns and low physical activity, resulting in a positive energy balance.[8 9] However, the environment in which individuals live has a strong influence on one's choice and adoption of health-enhancing behaviors.[6 7 10 11] For example, residence in poor neighborhoods has been associated with a higher risk of overweight/obesity, irrespective of individual-level socioeconomic status.[12] Neighborhood deprivation has been associated with high availability of energy-dense food outlets, low availability of fruit and vegetable outlets and limited public sporting facilities. The influence of neighborhood deprivation is not limited to overweight/obesity. It has also been linked to various poor behavioral and health outcomes like drug abuse, cardiovascular diseases, and poor mental health including depression.[13 14] Thus, improving neighborhoods socioeconomic status (NSES) has been recommended as a potential strategy for the prevention and control of the current obesity epidemics as well as other chronic illnesses.[13 14]

There are a number of empirical studies on the link of neighborhood economic deprivation to higher risks or odds of overweight/obesity. The studies were, however, inconsistent in their findings. Some studies have reported a null association,[15 16] while other reported a strong association between poor NSES and overweight/obesity.[17 18] To date, there is no meta-analysis report on the association of NSES with overweight or obesity. Synthesizing the existing evidence would provide a summary estimate on the association and contribute to filling the gap in the literature. It may also facilitate evidence-based decision making as there is a better recognition of systematic review and meta-analysis findings in policy and decision making processes. Thus, in this work, we reviewed and meta-analyzed studies that reported on the association of NSES with overweight and obesity.

Methods

We conducted this systematic review and meta-analysis according to a priorly published study protocol[19] and following recommendations of the Meta-analysis of Observational Studies in Epidemiology (MOOSE)[20] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[21] guidelines. The review protocol was also registered with the International Prospective Register of Systematic Reviews, registration number CRD42017063889.

Literature search and eligibility criteria

We searched five databases: EMBASE, PubMed, Scopus, Web of Sciences and Google Scholar, for studies published from inception to January 15, 2018. The search terms used included 'neighborhood socioeconomic status', 'neighborhood socioeconomic condition', 'neighborhood socioeconomic index', 'neighborhood deprivation index', 'neighborhood poverty index', 'obesity', 'overweight', 'body mass index', 'weight', and 'central obesity'. A sample of the search strategy, PubMed search strategy, developed using a combination of MeSH terms and free texts is presented (supplementary file 1). The PubMed search strategy was further adapted to the other databases: EMBASE, Scopus, Web of Sciences, and Google Scholar. We also hand searched articles, using the reference lists of the eligible studies and the 'cited by' function of PubMed. We aimed to include both observational and interventional studies (cross-sectional, case-control, cohort, longitudinal, and randomized control studies). The search was not restricted by sex, age, geographic location, or study year. Articles were excluded on any one of the following conditions: (1) animal studies, (2) study focused primarily on physical, policy, or social aspects of the environment, (3) language other than English, (4) citations without full text, (5) studies in which

the outcome measure was not overweight or obesity, and (6) qualitative studies, book chapters, symposium and conference proceedings, essays, commentaries, editorials, and case reports.

Study screening and data extraction

The results of database searches were exported to EndNote X8 software to remove duplicates and manage the screening process. Titles and abstracts of retrieved studies were assessed by two reviewers (SHM, TDH), working independently and in duplicate, to determine their eligibility for full-text reviewing. Full text reviewing was done by SHM and TDH. Disagreement on the eligibility of studies was resolved by consensus. The process of article screening and selection is presented in Figure 1 [refer to Figure 1: PRISMA flow diagram]. SHM, extracted the data, double checked by TDH. Data extracted from included studies were (1) study identification (first author, year of publication, and title), (2) study characteristics (country, study design, sample size, and follow-up period for longitudinal studies), (3) study participant's characteristics (sex, proportion of men, and mean age), (4) NSES assessment method, (5) outcome assessment method, (6) measure of association and reported estimates, and (7) variables used for adjustment. The predefined measures of association were RR or OR of overweight or obesity among individuals living in poor neighborhoods, compared with individuals living in better-off neighborhoods. When studies reported more than one estimate, we took the estimate that was adjusted for more variables. When studies reported multiple NSES comparisons, we took the estimate which compared the highest and the lowest NSES categories.

Study quality assessment

We evaluated the methodological quality of the included studies using the Newcastle-Ottawa Scale (NOS)[22]. The grading was out of 9, with scores from 0 to 3 considered low quality, from 4

to 6 medium quality, and from 7 to 9 high quality. The ratings for each study were compared between the two evaluators (SHM, TDH) with discrepancy resolved by consensus.

Statistical analysis

Separate meta-analyses were done for the outcome measures: overweight and obesity. Most studies reported using OR as a measure of association. Thus, in this work, OR was used to pool the estimates reported by the included studies. The OR represents the risk of developing overweight or obesity among individuals living in poor neighborhoods (low NSES), compared with individuals living in affluent neighborhoods (high NSES). For all estimates, if P-values were reported as P<0.001 with no 95%CI or standard error (SE) report, we assumed P=0.001 to calculate the corresponding 95%CI and SE. Heterogeneity among the studies was assessed by I^2 statistics, which estimate the proportion of variance attributable to between-studies heterogeneity. A non-substantial level of statistical heterogeneity was assumed when P<0.1 or I^2<50%.[23] Source of heterogeneity was assessed by conducting subgroup analyses using the predefined potential sources of heterogeneity as outlined in the study protocol,[19] which were age category (adults versus children), region/continent, study design, and methods of NSES measurements. Due to a persisting high level of heterogeneity even after subgrouping, we calculated the summary estimates with the random effects model, which accounts for both within and between studies variations. We aimed to assess publication bias by visual inspection of funnel plots and Egger's regression test.[24] According to Egger's test of asymmetry of funnel plots, publication bias is assumed at P<0.1.[24] To evaluate the influence of each study on the summary estimates, we conducted sensitivity analyses using the leave-one-out and analyses the rest method. Stata version 15.0 software was used for all analyses.

Result

Search result and study characteristics

The search strategy generated a total of 2,375 studies. Screening the title and abstract of these studies resulted in 79 studies eligible for full-text review. Reviewing the full text of the 79 studies, resulted in eight eligible articles. Through hand searching of the references of the included studies and the 'cited by' function of PubMed and Google Scholar, two additional articles were identified. The flowchart of the screening and selection process is shown in Figure 1. The main characteristics of the included studies are presented in Table 1. The sample size of the studies ranged from 144 to 948,062 individuals. In total, the 10 studies[15-18 25-30] included a total of 1,151, 409 unique individuals of all age categories, of whom 53.13% were males and 46.87% females. The mean age of study participants was 43.92 years. The studies were published from 2005 to 2016. The majority of the studies, 7/10 (70.00%), were cross-sectional in design and 3/10 (30.00%) longitudinal. All studies were conducted in high-income countries: 3 in USA, 1 in Canada, 2 in Germany, 3 in Sweden, and 1 in New Zealand.

Table 1: General characteristics included studies.

First author (year)	Country	Region	Study design	Follow-up	Sample (n)	Mean age	Men(%)	Population	NSES‡ measure	Weight measure
Amber (2014)[17]	New Zealand	Australia	CS	None	12488	47.00	53.00	Adults	NDI	Obesity
Steffen (2016)[25]	Germany	Europe	CS	None	3499	6.00	53.00	Children	NSESI	Obesity
Catherine (2006)[15]	Sweden	Europe	CS	None	18081	44.60	49.20	Adults	NDI	Obesity
Steven (2016)[26]	USA	America	LS	24 years	11499	10.31	51.00	Children	NDI	Obesity
Patricia (2010)[27]	USA	America	LS	10 years	48359	NA	0.00	Adults	NSESI	Obesity
Andrea (2016)[16]	USA	America	CS	None	144	26.40	100.00	Adults	NDI	Obesity

Xinjun (2014)[28]	Sweden	Europe	LS	10 years	948062	8.60	51.30	Children	NDI	Obesity
Steffen (2016)[18]	Germany	Europe	CS	None	3499	6.00	53.00	Children	NSESI	Overweight
Lisa (2005)[29]	Canada	America	CS	None	11455	11.80	50.80	Children	NDI	Overweight
Eva (2009)[30]	Sweden	Europe	CS	None	94323	31.40	100.00	Adults	NSESI	Obesity

LS=longitudinal, CS=cross-sectional, NSES= Neighborhood socioeconomic status, NDI = Neighborhood deprivation index

Association of NSES with overweight

We found two studies which reported on the link of NSES to overweight, body mass index (BMI)>25 kg/m^2. The summary odds of overweight associated with living in poor neighborhoods was 30% higher, compared with residence in better-off neighborhoods (pooled OR=1.30, 95%CI=1.16-1.47, P<0.001) with no evidence significant heterogeneity (I^2=0.00%, P=0.609). Figure 2 presents the result of the meta-analysis of the NSES-overweight association.

Association of NSES with Obesity

We found eight studies which reported on the association of NSES with obesity, BMI≥30 kg/m^2. The odds of being obese was 43% higher in individuals living in poor neighborhoods, compared with that of individuals living in better-off neighborhoods (pooled OR=1.43, 95%CI=1.18-1.74, P<0.001). Figure 3 shows the forest plot and summary estimate of the meta-analysis of the NSES-obesity association. There was a high level of heterogeneity among the studies (I^2=93.00%, P<0.001). We explored the sources of the heterogeneity by doing subgroup analyses. However, the level of heterogeneity remained high even after the subgroups analyses. The subgroup-specific summary estimates with their corresponding levels of heterogeneity are presented in Figure 4. Across the three continents, Australia, America, and Europe, NSES maintained a significant association with obesity (P<0.05). In children, residence in poor neighborhoods was

associated with a 1.57 times higher odds of obesity compared to children living in better of neighborhoods. The association was not significant, albeit largely towards being significantly associated (pooled OR=1.57, 95%CI=0.98-2.51). In adults, poor NSES was associated a significantly higher odds of obesity, such that the odds of obesity was 1.37 times higher in individuals living in poor neighborhoods, compared with individuals living in better-off neighborhoods (pooled OR=1.37, 95%CI=1.11-1.68). By study designs, NSES was significantly linked to obesity in cross-sectional studies, but not in longitudinal studies.

It was not possible to assess publication bias on the NSES-obesity as there was an inadequate number of studies which under-powered any of the statistical methods to assess publication bias. A minimum of eight studies is needed to assess publication bias. To evaluate the influence of each study on the summary estimate, we conducted sensitivity analyses (Table 2). Overall, no study notably changed of the direction and magnitude the association, with the summary OR ranging from lowest 1.29 (95%CI=1.10-1.48) after excluding Xinjun et al.[28] to highest 1.50 (95%CI=1.21-1.78) after excluding Steven et al. [26]

Table 2: Sensitivity analysis of studies on the association of neighborhood socioeconomic status with obesity

Study omitted	Pooled OR	95% CI
Amber (2014)[17]	1.49	1.16-1.81
Catherine (2006)[15]	1.43	1.16-1.69
Xinjun (2014)[28]	1.29	1.10-1.48
Steffen (2016)[25]	1.35	1.12-1.57

Steven (2016)[26]	1.50	1.21-1.78
Andrea (2016)[16]	1.39	1.16-1.62
Eva (2009)[30]	1.32	1.10-1.55
Patricia (2010)[27]	1.41	1.16-1.67

OR=odds ratio, CI=confidence interval

Discussion

The study was aimed to pool the existing empirical studies on the link of NSES to overweight and obesity. Overall, NSES was found significantly associated with overweight/obesity, such that residence in economically deprived neighborhoods was associated with significantly higher odds of overweight and obesity. The association remained significant across populations of three continents: North America, Australia, and Europe. However, there was variation in the NSES-obesity association by study design and age sub-groups.

The findings of this work were consistent with the reports of previous empirical studies which reported a higher odds of overweight/obesity as well as other adverse health outcomes among individuals living in poor neighborhoods.[18 28 29] The mechanisms through which NSES contributes to the development of overweight/obesity have not been thoroughly documented. However, various potential mechanisms have been suggested to explain the link. The most frequently mentioned mechanisms is the 'obesogenic environment' hypothesis that poor neighborhoods promote unhealthy lifestyles, particularly unhealthy dietary practice and sedentariness.[12 31]

Health-enhancing facilities and options are often limited in poor neighborhoods but junk food items, alcohol, and drug are more readily available.[31 32] Streets walkability and safety are more compromised; thus, limiting the resident's movement.[11 33] A multinational study in Europe showed that physical inactivity and unhealthy eating jointly accounted for one-fifth of the NSES-BMI association.[34] Another potential, but not a thoroughly examined mechanism, is the 'stress and depression hypothesis' that stress and depression could result in an unhealthy lifestyle and subsequently lead to a higher risk of overweight/obesity.[32] Provided poor neighborhood economic conditions have been related to a higher risk of depression,[32] it could be presumed that depression may mediate the link of NSES to overweight/obesity. Despite the ongoing debate on which these factors deserve the most responsibility in the link between NSES and overweight/obesity, most factors are believed to influence weight mainly through tipping the energy balance towards gaining more calorie. However, whether the energy dynamics mediate the NSES-BMI link has not been well established and requires further investigation.[9-11]

The finding of this study might be indicative of the importance of investigating as well as addressing the determinants of overweight/obesity comprehensively, i.e., examining not only the proximal behavioral factors but also the underlying environmental and structural factors. However, the existing literature is largely focused on identifying or addressing the individual level behavioral influences.[7] For example, the evidence is limited about how, and to what extent, neighborhood socioeconomic conditions influence individuals' dietary practice and level of physical activity. Whether improving neighborhood economic deprivation results in the adoption of health-enhancing lifestyle also remains largely unknown. Besides, the existing evidence on NSES-obesity association, including the report of this work, is largely based on observational studies.

Thus, further randomized controlled, community-based studies are needed to reach a more conclusive conclusion. Meanwhile, it might be worthy of considering a comprehensive approach in policy-making with regard to obesity prevention and control strategies, including addressing disparities in neighborhood economic disparities. So far, obesity interventions have been selectively focused on providing information to address the individual-level determinants. However, unless supported by an enabling environment, provision of health information alone might not lead to the intended result. Thus, the lack of comprehensiveness and integrity of interventions might partly explain the current non-promising progress in obesity prevention and control approaches.[4 33] Poor neighborhoods often lack healthy weight promoting amenities, like sporting facilities and fruit/vegetable outlets.[31] We believe that addressing neighborhood deprivation by availing healthy choices closer and affordable to everyone, might facilitate the adoption of health-enhancing behaviors, thereby reducing the risk of overweight/obesity. However, the proposition needs to be further evaluated.

Limitations and Strengths

The work has many limitations. The lack of uniformity in NSES measures and covariates used for adjustment might have introduced heterogeneity and undermined the comparability of the studies. All studies included in this work were done in high-income countries. The lack of data from low- and middle- income countries would limit the generalizability of the findings beyond the developed nations as NSES-obesity association would vary by countries' socioeconomic status. In developing countries, due to the traditionally held positive attitude toward overweight, low NSES might be associated with a lower risk of overweight/obesity, unlike the case in the developed

nations. Therefore, the findings of this work might not be applicable to developing countries. The association of NSES with BMI in continuous scale was not assessed in this study. All studies included in this work were observational in design, making casual inference impossible. Reverse causality cannot be ruled out; i.e., instead of better-off neighborhoods promoting healthy weight, it is possible that individuals with a healthy weight are more interested in health, and therefore, prefer living in better-off neighborhoods. To the best of our knowledge, this study is the first systematic review and meta-analysis report on the link of NSES to overweight/obesity. Thus, it would be contributing to filling the existing gap in the literature. The inclusion of multi-national studies, a large number of study participants and individuals of all age groups could improve the representativeness of the study.

Conclusion

We found that living in economically deprived neighborhoods, compared to living in better-off neighborhoods, was associated with an overall higher odd of overweight or obesity. Evidence on the association of NSES and overweight/obesity is missing in low and middle-income regions. The exact mechanism by which NSES contributes to unhealthy weight, and whether addressing NSES disparity reduces the risk of obesity is unclear. Further studies are warranted to understand better how NSES influences weight and whether addressing NSES disparity reduce the risk of overweight/obesity. Meanwhile, addressing neighborhoods economic disparity and bringing healthy choices closer and affordable to everyone would be worthy of consideration.

Funding

This research received no specific grant from any funding agency in public, commercial or not-for-profit sectors.

Competing interest

None declared.

Patient consent

This study was based on extracting data from published studies.

Data sharing statement

All data are included in the study.

References

1. World Health Organization. Obesity and overweight fact sheet. 2014 http://www.who.int/mediacentre/factsheets/fs311/en/ (accessed 29 August 2018).

2. Alleyne G, Binagwaho A, Haines A, et al. Embedding non-communicable diseases in the post-2015 development agenda. Lancet 2013;381(9866):566-74.

3. Hulsegge G, Picavet HS, Blokstra A, et al. Today's adult generations are less healthy than their predecessors: generation shifts in metabolic risk factors: the Doetinchem Cohort Study. Eur J Prev Cardiol 2014;21(9):1134-44.

4. Roberto CA, Swinburn B, Hawkes C, et al. Patchy progress on obesity prevention: emerging examples, entrenched barriers, and new thinking. Lancet 2015;385(9985):2400-9.

5. Booth KM, Pinkston MM, Poston WS. Obesity and the built environment. J Am Diet Assoc 2005;105(5 Suppl 1):S110-7.

6. Lipek T, Igel U, Gausche R, et al. Obesogenic environments: environmental approaches to obesity prevention. J Pediatr Endocrinol Metab 2015;28(5-6):485-95.

7. Papas MA, Alberg AJ, Ewing R, et al. The built environment and obesity. Epidemiol Rev 2007;29:129-43.

8. Hall KD, Heymsfield SB, Kemnitz JW, et al. Energy balance and its components: implications for body weight regulation. Am J Clin Nutr 2012;95(4):989-94.

9. Hill JO. Understanding and addressing the epidemic of obesity: an energy balance perspective. Endocr Rev 2006;27(7):750-61.

10. Cohen DA. Obesity and the built environment: changes in environmental cues cause energy imbalances. Int J Obes (Lond) 2008;32 Suppl 7:S137-42.

11. Popkin BM, Duffey K, Gordon-Larsen P. Environmental influences on food choice, physical activity and energy balance. Physiol Behav 2005;86(5):603-13.

12. Wang MC, Kim S, Gonzalez AA, et al. Socioeconomic and food-related physical characteristics of the neighbourhood environment are associated with body mass index. J Epidemiol Community Health 2007;61(6):491-8.

13. Chetty R, Hendren N, Katz LF. The Effects of Exposure to Better Neighborhoods on Children: New Evidence from the Moving to Opportunity Experiment. Am Econ Rev 2016;106(4):855-902.

14. Ellaway A, Benzeval M, Green M, et al. "Getting sicker quicker": does living in a more deprived neighbourhood mean your health deteriorates faster? Health Place 2012;18(2):132-7.

15. Cubbin C, Sundquist K, Ahlen H, et al. Neighborhood deprivation and cardiovascular disease risk factors: protective and harmful effects. Scand J Public Health 2006;34(3):228-37.

16. Cassidy-Bushrow AE, Peters RM, Burmeister C, et al. Neighborhood-Level Poverty at Menarche and Prepregnancy Obesity in African-American Women. Journal of pregnancy 2016;2016:4769121.

17. Pearson AL, Bentham G, Day P, et al. Associations between neighbourhood environmental characteristics and obesity and related behaviours among adult New Zealanders. BMC Public Health 2014;14:553.

18. Schüle SA, Von Kries R, Fromme H, et al. Neighbourhood socioeconomic context, individual socioeconomic position, and overweight in young children: A multilevel study in a large German city. BMC Obesity 2016;3(1).

19. Mohammed SH, Birhanu MM, Sissay TA, et al. What does my neighbourhood have to do with my weight? A protocol for systematic review and meta-analysis of the association between neighbourhood socioeconomic status and body weight. BMJ Open 2017;7(9):e017567.

20. Stroup DF, Berlin JA, Morton SC, et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. JAMA 2000;283(15):2008-12.

21. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. J Clin Epidemiol 2009;62(10):1006-12.

22. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. Eur J Epidemiol 2010;25(9):603-5.

23. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med 2002;21(11):1539-58.

24. Mavridis D, Salanti G. How to assess publication bias: funnel plot, trim-and-fill method and selection models. Evid Based Ment Health 2014;17(1):30.

25. Schüle SA, Fromme H, Bolte G. Built and socioeconomic neighbourhood environments and overweight in preschool aged children. A multilevel study to disentangle individual and contextual relationships. Environmental Research 2016;150:328-36.

26. Alvarado SE. Neighborhood disadvantage and obesity across childhood and adolescence: Evidence from the NLSY children and young adults cohort (1986-2010). Social science research 2016;57:80-98.

27. Coogan PF, Cozier YC, Krishnan S, et al. Neighborhood socioeconomic status in relation to 10-year weight gain in the black women's health study. Obesity 2010;18(10):2064-65.

28. Li X, Memarian E, Sundquist J, et al. Neighbourhood deprivation, individual-level familial and socio-demographic factors and diagnosed childhood obesity: a nationwide multilevel study from Sweden. Obes Facts 2014;7(4):253-63.

29. Oliver LN, Hayes MV. Neighbourhood socio-economic status and the prevalence of overweight Canadian children and youth. Can J Public Health 2005;96(6):415-20.

30. Sellstrom E, Arnoldsson G, Alricsson M, et al. Obesity prevalence in a cohort of women in early pregnancy from a neighbourhood perspective. BMC Pregnancy Childbirth 2009;9:37.

31. Schneider S, Gruber J. Neighbourhood deprivation and outlet density for tobacco, alcohol and fast food: first hints of obesogenic and addictive environments in Germany. Public Health Nutr 2013;16(7):1168-77.

32. Gary-Webb TL, Baptiste-Roberts K, Pham L, et al. Neighborhood socioeconomic status, depression, and health status in the Look AHEAD (Action for Health in Diabetes) study. BMC Public Health 2011;11:349.

33. Townshend T, Lake A. Obesogenic environments: current evidence of the built and food environments. Perspect Public Health 2017;137(1):38-44.

34. Compernolle S, Oppert JM, Mackenbach JD, et al. Mediating role of energy-balance related behaviors in the association of neighborhood socio-economic status and residential area density with BMI: The SPOTLIGHT study. Prev Med 2016;86:84-91.

Figures

Figure 1: PRISMA flow diagram.

Figure 2: Forest plot of association of neighborhood socioeconomic status with overweight.

Figure 3: Forest plot of association of neighborhood socioeconomic status with obesity.

Figure 4: Forest plot of association of neighborhood socioeconomic status with obesity, by subgroups.

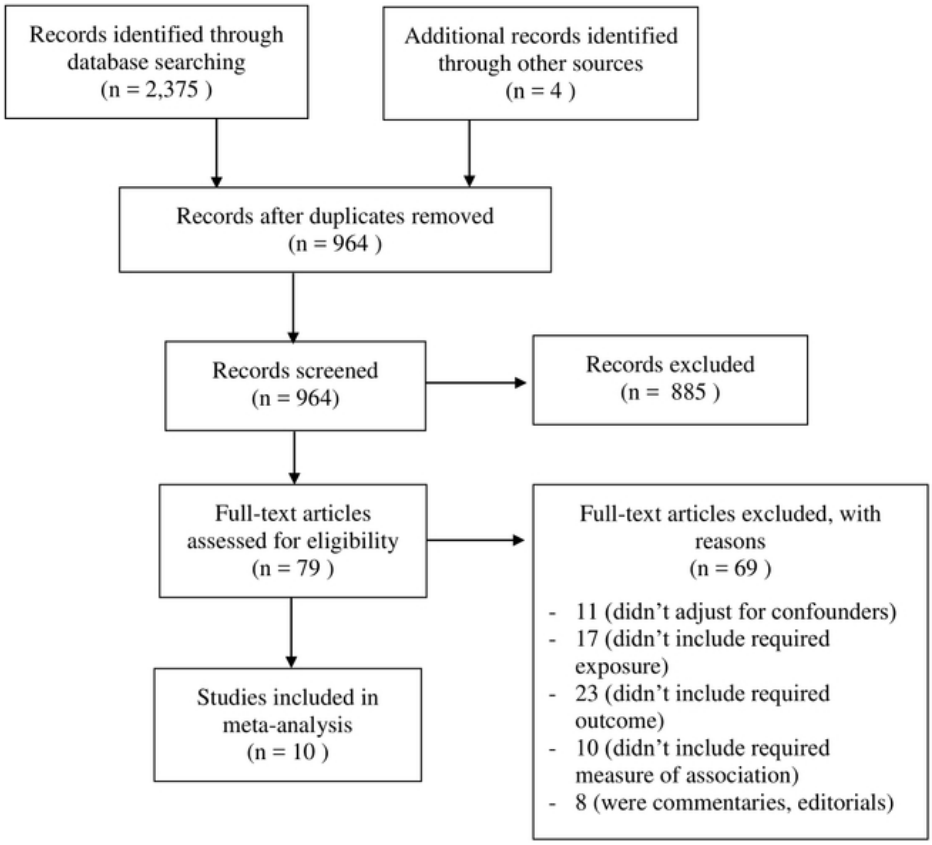

Figure 1: PRISMA flow diagram.

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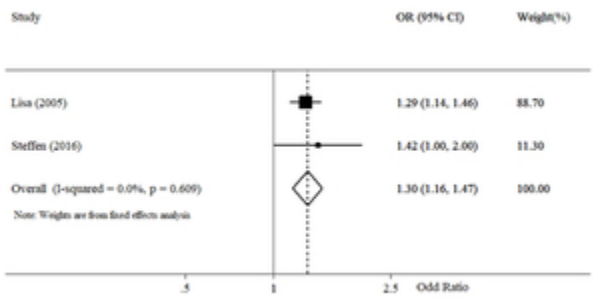

Figure 2: Forest plot of association of neighborhood socioeconomic status with overweight.

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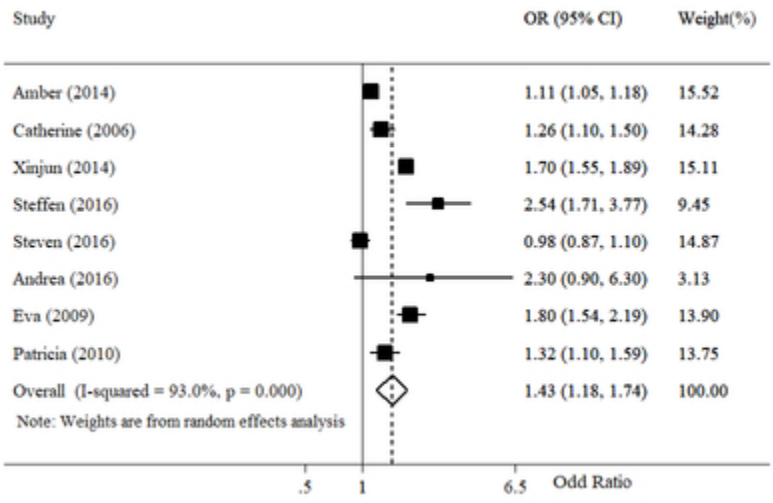

Figure 3: Forest plot of association of neighborhood socioeconomic status with obesity.

34x24mm (300 x 300 DPI)

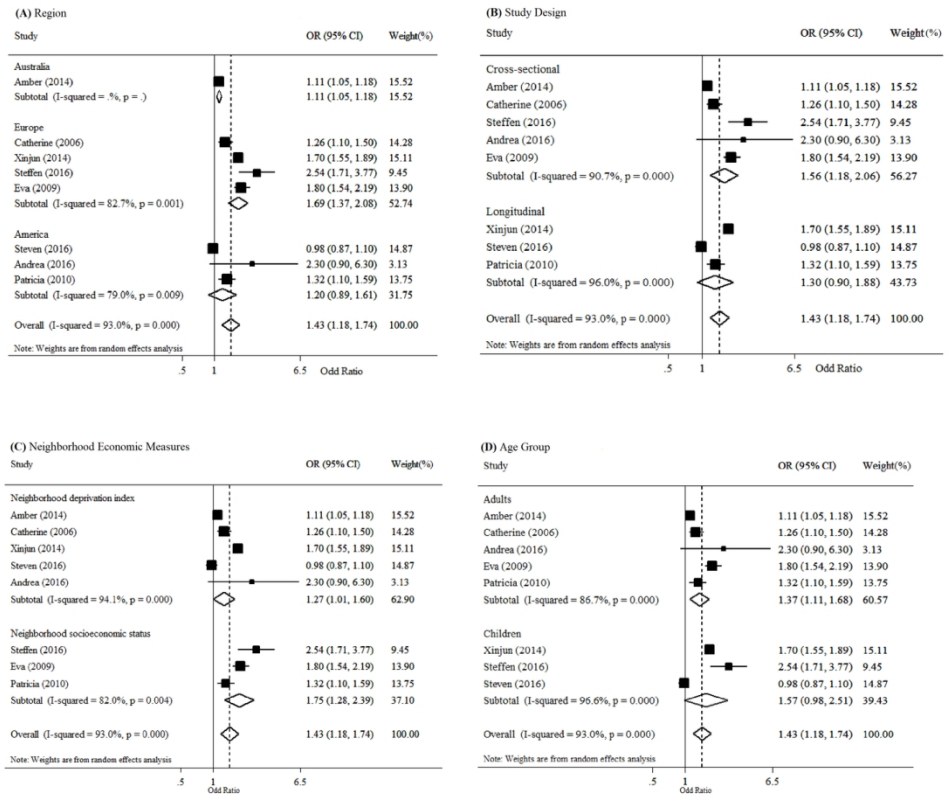

Figure 4: Forest plot of association of neighborhood socioeconomic status with obesity, by subgroups.

129x107mm (300 x 300 DPI)

PubMed Search strategy

Search	Query	Hits*
#1	(((((((Body Weight[MeSH Terms]) OR Body Mass Index[MeSH Terms]) OR Body weight[Title/Abstract]) OR Weight[Title/Abstract]) OR Obesity[Title/Abstract]) OR Overweight[Title/Abstract]) OR Over-weight[Title/Abstract]) OR BMI[Title/Abstract]	1049827
#2	((((((((((((Residence Characteristics/statistics and numerical data[MeSH Terms]))) OR Residence Characteristics/standards[MeSH Terms]) OR Residence Characteristics/economics[MeSH Terms]) OR Poverty Areas[MeSH Terms]) OR neighborhood socioeconomic*[Title/Abstract]) OR neighbourhood socioeconomic *[Title/Abstract]) OR neighborhood-level socioeconomic*[Title/Abstract]) OR neighbourhood-level socioeconomic*[Title/Abstract]) OR neighborhood socio-economic*[Title/Abstract]) OR neighbourhood socio-economic *[Title/Abstract]) OR neighborhood-level socio-economic*[Title/Abstract]) OR neighbourhood-level socio-economic*[Title/Abstract]	15170
#3	#1 AND #2	2375

*= *Date of search: June 30, 2018*

PRISMA Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4-5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	4-5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5-6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	5-6
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	5-6
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	6-7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	6

PRISMA Checklist

Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (I^2) for each meta-analysis.	6

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	6-7
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	6-7
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7-8
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7-8
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	8
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	7-8
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	7-8
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	8-9
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	8-9
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	9-11
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	11
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	11
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	12

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097.

PRISMA Checklist

doi:10.1371/journal.pmed1000097

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BMJ Open

Neighborhood socioeconomic status and overweight/obesity: a systematic review and meta-analysis of epidemiological studies

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-028238.R1
Article Type:	Original research
Date Submitted by the Author:	23-Jul-2019
Complete List of Authors:	Mohammed, Shimels Hussien; Tehran University of Medical Sciences, Department of Community Nutrition, School of Nutritional Sciences and Dietetics Habtewold, Tesfa; University of Groningen, Epidemiology; Debre Berhan University, Nursing Birhanu, Mulugeta ; Monash University, Department of Medicine, School of Clinical Sciences at Monash Health Sissay, Tesfamichael Awoke ; Addis Ababa University, Department of Public Health, School of Public Health Tegegne, Balewgizie; University of Groningen, Department of Epidemiology, University Medical Center Groningen Abuzerr, Samer; Tehran University of Medical Sciences, Department of Environmental Health Engineering, Faculty of Public Health Esmaillzadeh, Ahmad; Tehran University of Medical Sciences; Tehran University of Medical Sciences, Obesity and Eating Habits Research Center, Endocrinology and Metabolism Molecular Cellular Sciences Institute,
Primary Subject Heading:	Nutrition and metabolism
Secondary Subject Heading:	Epidemiology, Public health
Keywords:	Obesity, Overweight, Body mass index, Neighborhood, Meta-analysis

Neighborhood socioeconomic status and overweight/obesity: a systematic review and meta-analysis of epidemiological studies

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Word count: 3,820

Abstract

Objective: Poor neighborhood socioeconomic status (NSES) has been linked to a higher risk of overweight/obesity, irrespective of individuals own socioeconomic status. However, there is no meta-analysis report is on the association. This study was aimed to synthesize the existing evidence on the association of NSES with overweight, obesity, and body mass index (BMI).

Design: Systematic review and meta-analysis.

Data sources: PubMed, Embase, Scopus, Cochrane Library, Web of Sciences and Google Scholar databases were searched for articles published until June 15, 2018.

Eligibility criteria: Epidemiological studies, both longitudinal and cross-sectional ones, which reported on the link of NSES to overweight, obesity or BMI were included.

Data extraction and synthesis: Data extraction and quality assessment were independently performed by two reviewers. The summary estimates of the relationships of NSES with overweight, obesity, and BMI statuses were calculated with random-effects meta-analysis models. Heterogeneity between the studies was assessed by Cochran's Q and I^2-statistics. Subgroup analyses were done by age categories, continents, study designs, and methods of NSES measures. Publication bias was assessed by visual inspection of funnel plots and Egger's regression test.

Result: A total of 20 studies, covering 1 240 608 individuals, were included in this meta-analysis. Residence in poor neighborhoods, compared to residence in better-off neighborhoods, was found associated with a 31% higher odds of overweight [pooled OR=1.31, 95% confidence interval (CI)=1.16-1.47, P<0.001], a 43% higher odds of obesity (pooled OR=1.43, 95%CI=1.18-1.74, P<0.001), and a 1.09 Kg/m^2 increase in mean BMI (pooled Beta=1.09, 95%CI=0.67-1.50, P<0.001).

Conclusion: NSES disparity might be a contributing factor to the burden of overweight/obesity. Further studies are warranted, including whether addressing neighborhood economic disparity reduces the risk of overweight/obesity.

PROSPERO Registration: CRD42017063889

Keywords: Neighborhood socioeconomic status, Obesogenic environment, Overweight, Obesity, Meta-analysis

Strengths and limitations

- This is the first meta-analysis study on the association of NSES with overweight/obesity.
- The report is based on a large number of studies, covering over a million individuals, which improves the representativeness of the sample and strength of the findings.
- The studies included are observational in design, precluding making causal inference.
- The estimates are based on mainly the western population, limiting the generalizability of the findings to other setups.

Introduction

Obesity remains a major global public health problem. While the current level of obesity has already posed a significant burden to the health system, the problem is still on the rise and causing more negative consequences at both individual and society levels.[1] Worldwide, 39% of adults were estimated to be overweight in 2016. In the same year, 13% of adults were estimated to be obese; almost triple of the figure in 1975.[1] The World Health Organization (WHO) has prioritized the prevention and control of obesity as a central public health agenda and recommends nations to make a substantial improvement with regard to the current trend of obesity.[2] However, the global progress to curb the rise and burden of overweight/obesity has been slow and frustrating, with each consecutive generation developing overweight/obesity at an early age and at higher rates.[3 4]

Overweight/obesity is a multi-causal problem, with its influences originating from various levels; including individual, social, and environmental origins. According to ecological models of obesity causation, the risk factors of overweight/obesity often interact with each other and might of direct and/or indirect influences on the weight status of individuals.[5-7] The main direct determinants are often unhealthy dietary patterns and low physical activity, resulting in a positive energy balance.[8 9] However, the environment in which individuals live has a strong influence on one's choice and adoption of health-enhancing behaviors.[6 7 10 11] For example,

residence in poor neighborhoods has been linked to a higher risk of overweight/obesity, irrespective of individual-level socioeconomic status.[12] There are various potential mechanisms through which neighborhood socioeconomic status (NSES) influences an individual's weight status. One of the most frequently mentioned mechanisms is the 'obesogenic environment' hypothesis that poor neighborhoods promote unhealthy dietary practice and sedentary lifestyle.[12 13] In poor neighborhoods, health-enhancing facilities and options are often limited in poor neighborhoods, but junk food, alcohol, and drug are more readily available.[13 14] Besides, streets walkability and safety might be compromised in poor neighborhoods; thus, limiting the residents' movement.[11 15] A multinational study in Europe showed that physical inactivity and unhealthy eating jointly accounted for almost a fifth of the NSES-BMI association.[16] Another potential, but not a thoroughly examined mechanism, is the 'stress hypothesis' that stress could lead to an unhealthy lifestyle, which subsequently leads to a higher risk of overweight/obesity.[14]

There are a number of empirical studies on the link of NSES to overweight, obesity, and BMI. The studies were, however, inconsistent in their findings. Some studies reported a null or weak association,[17 18] while other studies reported a strong association between NSES and overweight/obesity.[19 20] To date, there is no systematic review and meta-analysis report on the association of NSES with overweight, obesity or BMI. Synthesizing the existing evidence would provide a summary estimate on the topic and contribute to filling the existing gap in the literature. It may also facilitate evidence-based decision making as there is a better recognition of systematic review and meta-analysis findings in policy and decision making processes. Thus, this study was aimed to provide summary estimates on the link of NSES to overweight, obesity, and BMI.

Methods

This systematic review and meta-analysis work was conducted according to a priorly published study protocol[21] and following the recommendations of the Meta-analysis of Observational Studies in Epidemiology (MOOSE)[22] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[23] guidelines. The review protocol was also registered with the International Prospective Register of Systematic Reviews, registration number CRD42017063889.

Literature search

Embase, PubMed, Scopus, Web of Sciences, Cochrane Library, and Google Scholar databases were searched for studies published until June 15, 2018. The search terms were 'neighborhood socioeconomic status', 'neighborhood socioeconomic condition', 'neighborhood socioeconomic index', 'neighborhood deprivation index', 'neighborhood poverty index', 'area deprivation', 'obesity', 'overweight', 'body mass index', 'weight', and 'central obesity'. A sample of the search strategy, PubMed search strategy, developed using a combination of MeSH terms and free texts is presented (supplementary file 1). The PubMed search strategy was further adapted to the other databases. Additionally, hand searching of articles was done using the reference lists of the eligible studies and the 'cited by' function of PubMed. We aimed to include both observational and interventional studies (cross-sectional, case-control, cohort, longitudinal, and randomized control studies). The literature search was not restricted by sex, age, or geographic location.

Study eligibility criteria

Articles found by the literature search were assessed whether they fulfilled the inclusion criteria of this work. The outcome variables of interest for this study were BMI (in Kg/m^2 and on a continuous scale), overweight, and obesity. The exposure variable of interest was NSES (measured by composite index). There is neither a uniform nor a standardized approach of NSES measurement. However, in the existing literature, NSES has been often considered as a composite index, developed based on the results of principal component analyses of variables with a potential to indicate neighborhoods' economic conditions. Some of the variables often used in the construction of NSES index are the proportion of households owned by residents, the proportion of employed residents, the value of assets in the area, property ownership by residents, availability of health-promoting amenities, and the literacy rate of the area. However, the specific set of variables used in the development of NSES indices often vary from one study to another depending on many contextual and statistical factors, including data availability and the result of the principal component analysis. To be included in this work, the study should be based on NSES measured by composite indices like neighborhood economic status indices (NSESI), neighborhood deprivation indices (NDI), or neighborhood economic hardship- indices (NEDI). The commonly used indices are NSESI and NDI, both of which could be used to rank neighborhoods into poor (deprived), middle, and rich (better-off) economic categories. Articles were excluded for any one of the following conditions: (1) animal studies, (2) study focused primarily on physical, policy, or social aspects of the environment, (3) language other than English, (4) citations without full text, (5) studies in which the outcome measure was not

overweight, obesity or BMI, and (6) qualitative studies, book chapters, symposium and conference proceedings, essays, commentaries, editorials, and case reports.

Study screening and data extraction

The results of the database search were exported to EndNote X8 software to remove duplicates and manage the screening processes. Then, the titles and abstracts of the retrieved studies were assessed by two reviewers (SHM, TDH), working independently and in duplicate, to determine their eligibility for full-text reviewing. The full text reviewing was done by SHM and TDH, with disagreement resolved by consensus. The process of article screening and selection is presented in Figure 1. SHM extracted the data, double-checked by TDH. The data extracted from included studies were (1) study identification (first author, year of publication, and title), (2) study characteristics (country, study design, sample size, and follow-up period for longitudinal studies), (3) study participant's characteristics (sex, proportion of men, and mean age), (4) NSES assessment method, (5) outcome assessment method, (6) measure of association and reported estimates, and (7) variables used for adjustment. The predefined measures of association were beta (β) of BMI, relative risk (RR), or odds ratio (OR). The beta (β) of BMI refers to the mean difference in BMI of individuals living in poor and rich neighborhoods. The OR refers to the odds of overweight or obesity among individuals living in poor neighborhoods, compared to individuals living in better-off neighborhoods. When studies reported more than one estimate, we took the estimate that was adjusted for more variables. When studies reported multiple NSES comparisons, we took the estimate which compared the highest and the lowest NSES categories.

Study quality assessment

The methodological quality of the studies was assessed using the Newcastle-Ottawa Scale (NOS) for grading the quality of observational studies.[24] The scale enabled to evaluate the studies on the bases of three parameters: (1) selection (assesses sample representativeness, sample size, non-response handling, and exposure ascertainment), (2) comparability (assesses comparability of study groups and confounding control), and (3) outcome (assesses ascertainment of outcome and appropriateness of statistical tests). The quality grading was done out of 9, with scores from 0 to 3 indicating low quality, 4 to 6 medium quality, and 7 to 9 high quality. The ratings for each study were compared between the two evaluators (SHM, TDH), with discrepancy resolved by consensus.

Statistical analysis

Separate meta-analyses were done for each of the three outcome measures: overweight, obesity, and BMI. OR was used to pool estimate of studies that reported on NSES-Overweight and NSES-Obesity associations, representing the odds of overweight or obesity among individuals living in poor neighborhoods (low NSES), compared to individuals living in better-off neighborhoods (high NSES). Beta (β) values from linear regression analyses, representing the mean increase in BMI due to change in NSES from high to low category, were used to pool the estimates of studies that used BMI, on a continuous scale, as an outcome measure. For all estimates, if P-values were reported as P<0.001 with no 95%CI or standard error (SE), we assumed P=0.001 in calculating the corresponding 95%CI and SE.

Heterogeneity among the studies was assessed by Cochran's Q and I^2-statistics, which estimate the proportion of variance attributable to between-studies heterogeneity. A non-substantial level of statistical heterogeneity was assumed when P<0.1 or I^2<50%.[25] Source of

heterogeneity was assessed by conducting subgroup analyses using the predefined potential sources of heterogeneity as outlined in the study protocol,[21] which were age category (adults versus children), study design (cross-sectional versus longitudinal), region (continent), and NSES measures. Due to a persistently high level of heterogeneity even after subgroup analyses, we calculated the summary estimates with random-effects model, which accounts for both within and between studies variations. Publication bias was assessed by visual inspection of funnel plots and Egger's regression test, unless as there was an inadequate number of studies which under-powered any of the statistical methods to assess publication bias. A minimum of ten studies is needed to ensure adequate power and assess publication bias.[26] According to Egger's test, publication bias is assumed at P<0.1.[26 27] For estimates with evidence of publication bias, we aimed to do adjustment following the Trim and Fill method [26 27] and provide both bias-adjusted and unadjusted pooled estimates. To evaluate the influence of each study on the summary estimates, we conducted sensitivity analyses using the leave-one-out and analyze the rest method. Stata version 15.0 software was used for all analyses.

Patient and public involvement

This work was based on extracting data from published studies. There was no patient and public involvement in the development of the research question, design, outcome measures, study implementation, and communication.

Result

Search result and study characteristics

The search strategy generated a total of 2 671 studies. Screening the title and abstract of these studies resulted in 89 studies eligible for full-text review. Reviewing the full text of the 89 studies, resulted in 17 eligible articles. Through hand searching for the references of the included studies and the 'cited by' function of PubMed and Google Scholar, three additional articles were identified. The flowchart of the screening and selection process is shown in Figure 1. The main characteristics of the 20 included studies[12 17-20 28-42] are presented in Table 1. The sample size of the studies ranged from 144 to 948 062 individuals, providing a total of 1 240 608 unique individuals, of whom 47% were males and 53% females. The mean age of the study participants was 43.92 years. The studies were published from 2005 to 2017. The majority of the studies, 13/20 (65%), were cross-sectional in design. The remaining 7 (35%) were longitudinal (cohort) studies. All studies were conducted in high-income countries: 7 in USA, 3 in Canada, 3 in Germany, 2 in Australia, 3 in Sweden, 1 in France, and 1 in New Zealand.

1

Table 1: General characteristics included studies.

First author (year)	Country	Study design	Follow-up (years)	Sample (n)	Mean age	Men (%)	Population	NSES‡ measure	Weight measure	Adjustment	NOS Scale
Amber (2014)[19]	New Zealand	CS	NA	12 488	47.00	53.00	Adults	NDI	Obesity	Age, sex, ethnicity, economic living standard index, individual-level deprivation, highest educational qualification, household composition, smoking status, alcohol consumption	8
Steffen (2016)[37]	Germany	CS	NA	3 499	6.00	53.00	Children	NSESI	Obesity	Birth weight, BMI of the mother, parental education, parental working status, household income, household crowding	9
Catherine (2006)[17]	Sweden	CS	NA	18 081	44.60	49.20	Adults	NDI	Obesity	Age, gender, marital status, immigration status, urbanization	6
Steven (2016)[38]	USA	LS	24	11 499	10.31	51.00	Children	NDI	Obesity	Age, sex	7
Patricia (2010)[39]	USA	LS	10	48 359	NA	0.00	Adults	NSESI	Obesity	Age, family income, marital status, exercise, energy intake, smoking	8
Andrea (2016)[18]	USA	CS	NA	144	26.40	100.00	Adults	NDI	Obesity	Maternal age, marital status, maternal education, parity	
Xinjun (2014)[40]	Sweden	LS	10	948 062	8.60	51.30	Children	NDI	Obesity	Age, family (income, history of obesity & diabetes), personal history of (chronic obstructive pulmonary disease, alcoholism & diabetes)	9
Eva (2009)[42]	Sweden	CS	NA	94 323	31.40	100.00	Adults	NSESI	Obesity	Age, sex, individual income, education status	9
Steffen (2016)[20]	Germany	CS	NA	3 499	6.00	53.00	Children	NSESI	Overweight	Birth weight, BMI of the mother, parental education, parental working status, household income, household crowding	7
Lisa (2005)[41]	Canada	CS	NA	11 455	11.80	50.80	Children	NDI	Overweight	Age, gender, family income, education level	8
TR Berry (2010)[28]	Canada	LS	6	500	42.81	52.00	Adults	NSESI	BMI	Age, sex	8
Xiaoqi (2015)[29]	Australia	LS	6	18 341	46.60	47.00	Adults	NDI	BMI	Age, sex, number of children in the household, household education status, household unemployment, annual household income	9
Paula (2011)[30]	USA	CS	NA	21 166	24.94	0.00	Adults	NDI	BMI	Tract supermarkets, tract small grocery stores, tract convenience stores, ethnicity, education, annual income statuses	8
Maria (2013)[31]	Germany	LS	4	485	5.81	51.72	Children	NSESI	BMI	Street type, perceived frequency of passing trucks and buses, street walkability	7

Cinira (2011)[32]	France	CS	NA	7 230	46.80	0.00	Adults	NSESI	BMI	Age, country human development index, individual education level, occupation, financial strain, cultural entertainments, health-related external locus of control, propensity to keep healthy resolutions	8
May (2007)[12]	USA	CS	NA	7 595	52.81	49.25	Adult	NDI	BMI	Age, gender, ethnicity, individual-level socioeconomic status, smoking, physical activity, nutrition knowledge	8
Lisa (2014)[33]	Canada	LS	8	2 152	2.48	50.44	Children	NSESI	BMI	Age, sex, income, education, family structure	8
Barbara (2012)[34]	USA	CS	NA	19 804	48.30	51.20	Adults	NDI	BMI	Race, sex, age, income, education level, marital status, nativity, individual socioeconomic status	8
Tali (2017)[35]	USA	CS	NA	1 645	49.00	42.00	Adults	NSESI	BMI	Age, race, education, poverty, employment status, physical activity	9
Xiaoqi (2017)[36]	Australia	CS	NA	10 281	44.70	47.60	Adults	NSESI	BMI	Gender, age	6

LS=Longitudinal, CS=Cross-sectional, NA=Not applicable, NSES=Neighborhood socioeconomic status, NDI=Neighborhood deprivation index, BMI=Body mass index,

NOS=Newcastle Ottawa scale

Association of NSES with overweight

We found two studies which reported on the link of NSES to overweight, BMI>25 kg/m^2. The summary odds of overweight, compared to being not overweight, was 30% higher in individuals living in poor neighborhoods, compared to that of individuals living in better-off neighborhoods (pooled OR=1.30, 95%CI=1.16-1.47, P<0.001). There was no evidence of significant heterogeneity (I^2=0.00%, P=0.609). Figure 2 presents the result of the meta-analysis of the NSES-overweight association.

Association of NSES with Obesity

We found eight studies which reported on the association of NSES with obesity, BMI≥30 kg/m^2. The odds of being obese, compared to being non-obese, was 43% higher in individuals living in poor neighborhoods, compared to that of individuals living in better-off neighborhoods (pooled OR=1.43, 95%CI=1.18-1.74, P<0.001). Figure 3 shows the forest plot and summary estimate of the meta-analysis of the NSES-obesity association. There was a high level of heterogeneity among the studies (I^2=93.00%, P<0.001). We explored the sources of the heterogeneity by doing subgroup analyses. The subgroup-specific summary estimates with their corresponding levels of heterogeneity are presented in Figure 4. Across the three continents where the studies were done, Australia, America, and Europe, NSES maintained a significant association with obesity (P<0.05). In children, residence in poor neighborhoods was associated with a 1.57 times higher odds of obesity compared to residence in better-off neighborhoods. The association was not significant, albeit largely towards being significantly associated (pooled OR=1.57, 95%CI=0.98-2.51). In adults, poor NSES was associated a significantly higher odds of obesity, such that the odds of obesity was 1.37 times higher in individuals living in poor neighborhoods,

compared to individuals living in better-off neighborhoods (pooled OR=1.37, 95%CI=1.11-1.68). In terms of study design, NSES was significantly linked to obesity in the cross-sectional studies, but not in the longitudinal studies. It was not possible to assess publication bias on the NSES-obesity association as there was an inadequate number of studies which under-powered any of the statistical methods to assess publication bias. A minimum of ten studies is needed to assess publication bias.[26] To evaluate the influence of each study on the summary estimate, we conducted sensitivity analyses (Table 2). Overall, no study notably changed of the direction as well as magnitude the NSES-Obesity association, with the summary OR ranging from the lowest 1.29 (95%CI=1.10-1.48) after excluding Xinjun et al.[40] to the highest 1.50 (95%CI=1.21-1.78) after excluding Steven et al.[38]

Table 2: Sensitivity analysis of studies on the association of neighborhood socioeconomic status with obesity

Study omitted	Pooled OR	95% CI
Amber (2014)[19]	1.49	1.16-1.81
Catherine (2006)[17]	1.43	1.16-1.69
Xinjun (2014)[40]	1.29	1.10-1.48
Steffen (2016)[37]	1.35	1.12-1.57
Steven (2016)[38]	1.50	1.21-1.78
Andrea (2016)[18]	1.39	1.16-1.62
Eva (2009)[42]	1.32	1.10-1.55
Patricia (2010)[39]	1.41	1.16-1.67

OR=odds ratio, CI=confidence interval

Association of NSES with BMI

Ten of the 20 studies included in this work reported on the relation of NSES with BMI. The summary estimate showed that NSES was significantly associated with BMI. The BMI of individuals living in poor neighborhoods was higher by a mean of 1.09 kg/m^2, compared to the BMI of individuals living in better-off neighborhoods (pooled β=1.09, 95%CI=0.67-1.50, P<0.001). Figure 5 shows the summary estimate of the association of NSES with BMI, calculated with random-effects model. There was a significant level of heterogeneity (I^2<0.001). Thus, subgroup analyses were conducted by the studies' design (cross-sectional versus longitudinal) and methods of NSES measurement. In all subgroup showed the mean BMI was significantly higher in poor neighborhoods than in better-off neighborhoods. Details of the results of the subgroup analyses by study design and NSES measurement methods are presented in Figure 6. The result of the Egger's regression test did not indicate the presence of a significant level of publication bias (P=0.903). The funnel plot of the NSES-BMI studies is shown in Figure 7. The result of the sensitivity analysis is shown in Table 3. Overall, no study notably influenced the direction as well as strength of the NSES-BMI association, with the pooled β ranging from the lowest 0.82 (95%CI=0.62-1.19) after excluding Xiaoqi (2015)[29] to the highest 1.14 (95%CI=0.68-1.60) after excluding TR Berry (2010).[28]

Table 3: Sensitivity analysis of studies on the association of NSES with BMI.

Study omitted	Pooled Beta	95% CI
TR Berry (2010)[28]	1.14	0.68-1.60
Xiaoqi (2015)[29]	0.90	0.62-1.19
Paula (2011)[30]	1.11	0.63-1.60
Maria (2013)[31]	1.19	0.80-1.58
Cinira (2011)[32]	1.04	0.59-1.50
May (2007)12	1.15	0.68-1.61

Lisa (2014)[33]	1.07	0.63-1.50
Barbara (2012)[34]	1.10	0.60-1.60
Tali (2017)[35]	1.06	0.63-1.49
Xiaoqi (2017)[36]	1.08	0.62-1.53

CI=confidence interval

Discussion

The study was aimed to pool the existing empirical evidence on the link of NSES to overweight, obesity, and BMI. Overall, NSES was found to be significantly associated with the three outcome measures, such that residence in poor neighborhoods was significantly linked to high odds of overweight, obesity, and elevated BMI.

The findings of this work were consistent with the reports of previous studies that reported higher odds of overweight/obesity as well as other poor health outcomes in individuals living in poor neighborhoods than in individuals living in better-off neighborhoods.[20 40 41] The influence of neighborhood deprivation is not limited to body weight. It has also been linked to various poor behavioral and health outcomes like drug abuse, cardiovascular diseases, and poor mental health.[43 44] Thus, improving NSES has been recommended as a potential strategy for the prevention and control of the current obesity epidemics as well as other chronic illnesses.[43 44] The mechanisms through which NSES contributes to the development of overweight/obesity have not been thoroughly documented. Despite the ongoing debate on which of the mediating factors deserves the most responsibility for the link of NSES to body weight, most factors are, however, believed to influence weight mainly through influencing the energy balance, i.e. the

balance of calorie intake and loss.[9-11] Poor neighborhoods have been associated with a high availability of energy-dense food outlets, but a low availability of fruit and vegetable outlets and limited sporting facilities. Poor neighborhoods have also been related to a higher risk of depression, which could subsequently lead to a higher risk of overweight/obesity.[14]

In this work, there was a discrepancy in the NSES-Obesity association between cross-sectional and longitudinal studies. The NSES-Obesity association was not statistically significant among longitudinal studies but statistically significant among cross-sectional ones. It is worth noting to the reader that the NSES-Obesity association was consistent across the other subgroup analyses by age (adults versus children), NSES measures (NSESI versus NDI), and outcome measures (overweight versus obesity). The discrepancy by study design was also not observed in the NSES-BMI association, in which NSES demonstrated significant statistical links to BMI in both longitudinal and cross-sectional studies. There are a number of possible reasons that could explain the discrepancy in NSES-Obesity association between cross-sectional and longitudinal studies. First, it could be due to the fact that only two longitudinal studies are included on NSE-Obesity association. Second, there was no uniformity in how confounding was controlled among the included studies, in terms of both the number and type of variables used for adjustment. This lack of uniformity across the studies in terms of the type and number of variables used for adjustment might in part explain the inconsistency in the NSES-Obesity summary estimates by study design. Third, it could also be due to the use of a dichotomized outcome variable (obesity), instead of a continuous outcome variable (BMI). Unless it is mandatory, dichotomization of continuous variables is not recommended as it reduces sample power by almost 50% and could result in false no association findings, particularly if the true association is

weak.[45 46] In support of this, we observed no discrepancy between cross-sectional and longitudinal studies in all NSES-BMI summary estimates, in which the outcome was BMI on a continuous scale. However, as none of the above reasons could definitively explain the NSES-Obesity discrepancy by study, we recommend further meta-analysis works when more longitudinal studies become available.

The finding of this study might indicate the importance of investigating as well as addressing the determinants of overweight/obesity comprehensively, i.e., examining and addressing not only the proximal behavioral factors but also the underlying environmental and other structural factors. However, the existing literature is largely focused on investigating the individual level behavioral influences.[7] For example, the evidence is limited about how, and to what extent, neighborhood socioeconomic conditions influence individuals' dietary practice and level of physical activity. Whether improving neighborhood economic deprivation results in the adoption of health-enhancing lifestyle also remains largely unknown. Besides, the existing evidence on the link of NSES to an unhealthy weight, including the report of this work, is largely based on observational studies. Thus, further investigations with better designs like community-based longitudinal studies are needed to reach a more conclusive conclusion. Meanwhile, it might be worthy of considering a comprehensive approach when developing obesity prevention and control strategies, including addressing neighborhood economic disparities. So far, obesity interventions have been largely focused on providing health information and strategies to address the individual-level determinants. However, unless supported by an enabling environment, the individual level efforts and provision of health information alone might not lead to the intended result as fast as needed. Thus, the lack of comprehensiveness and integrity of

interventions might partly explain the current non-promising progress in obesity prevention and control approaches.[4 15] Poor neighborhoods often lack healthy weight-promoting amenities, like sporting facilities and fruit/vegetable outlets.[13] We believe that addressing neighborhood deprivation by availing healthy choices closer and affordable to everyone, might facilitate the adoption of health-enhancing behaviors, thereby reducing the risk of overweight/obesity. However, the proposition needs to be further evaluated.

Limitations and strengths

This work has many limitations. There was no uniformity among the studies in the way NSES was measured. Though all studies included in this work measured NSES as a composite variable, the specific set of variables used to develop the NSES indices varied from one study to another. There was also variation across the individual studies in the type and number of covariates used for adjustment of reported estimates. The lack of uniformity in NSES measures and covariate adjustment might have introduced heterogeneity and undermined the comparability of the studies. All studies included in this work were done in high-income countries. The lack of data from low- and middle- income countries would limit the generalizability of the findings. NSES-obesity association would vary by countries' socioeconomic status. In developing countries, due to the traditionally held positive attitude toward overweight, low NSES might be associated with a lower risk of overweight/obesity, unlike the case in the developed nations. Therefore, the findings of this work might not be applicable to developing countries. All studies included in this work were observational in design, making casual inference impossible. Besides, reverse causality could not be ruled out;

i.e. instead of better-off neighborhoods promoting healthy weight, it is possible that individuals with a healthy weight are more interested in health, and therefore prefer living in better-off neighborhoods. To the best of our knowledge, this study is the first systematic review and meta-analysis report on the link of NSES to overweight, obesity, and BMI. Thus, it would be contributing to filling the existing gap in the literature. The inclusion of multi-national studies, a large number of study participants and individuals of all age groups could improve the representativeness of the study.

Conclusion

We found that living in poor neighborhoods, compared to living in better-off neighborhoods, was associated with higher odds of being overweight and obese as well as a higher mean BMI. Evidence on the association of NSES with weight status is largely missing in low and middle-income countries. The exact mechanism by which NSES contributes to unhealthy, and whether addressing NSES disparity reduces the risk of obesity, is unclear. Thus, further studies are warranted to better understand how NSES influences weight and whether addressing NSES disparity could reduce the risk of overweight/obesity. Meanwhile, addressing NSES disparity and bringing healthy choices closer and affordable to everyone might stand worthy of programmatic consideration to curb the current trend of obesity.

Authors' contribution

SHM conceived and designed the study. SHM and TDH carried out literature search, performed quality assessment of included studies, analyzed data and prepared the manuscript. TAS, MMB, BST, and SA performed literature search, screening, data extraction, and quality assessment as second reviewers and critically reviewed the draft manuscript. AE supervised the study. All the authors read, commented and approved the final manuscript.

Funding

This research received no specific grant from any funding agency in public, commercial or not-for-profit sectors.

Competing interest

None declared.

Data sharing statement

All the data used in the study are included the article.

Patient consent

Not required as the study was based on extracting data from published studies.

References

1. World Health Organization. Obesity and overweight fact sheet. 2014 http://www.who.int/mediacentre/factsheets/fs311/en/ (accessed 29 August 2018).

2. Alleyne G, Binagwaho A, Haines A, et al. Embedding non-communicable diseases in the post-2015 development agenda. Lancet 2013;381(9866):566-74.

3. Hulsegge G, Picavet HS, Blokstra A, et al. Today's adult generations are less healthy than their predecessors: generation shifts in metabolic risk factors: the Doetinchem Cohort Study. Eur J Prev Cardiol 2014;21(9):1134-44.

4. Roberto CA, Swinburn B, Hawkes C, et al. Patchy progress on obesity prevention: emerging examples, entrenched barriers, and new thinking. Lancet 2015;385(9985):2400-9.

5. Booth KM, Pinkston MM, Poston WS. Obesity and the built environment. J Am Diet Assoc 2005;105(5 Suppl 1):S110-7.

6. Lipek T, Igel U, Gausche R, et al. Obesogenic environments: environmental approaches to obesity prevention. J Pediatr Endocrinol Metab 2015;28(5-6):485-95.

7. Papas MA, Alberg AJ, Ewing R, et al. The built environment and obesity. Epidemiol Rev 2007;29:129-43.

8. Hall KD, Heymsfield SB, Kemnitz JW, et al. Energy balance and its components: implications for body weight regulation. Am J Clin Nutr 2012;95(4):989-94.

9. Hill JO. Understanding and addressing the epidemic of obesity: an energy balance perspective. Endocr Rev 2006;27(7):750-61.

10. Cohen DA. Obesity and the built environment: changes in environmental cues cause energy imbalances. Int J Obes (Lond) 2008;32 Suppl 7:S137-42.

11. Popkin BM, Duffey K, Gordon-Larsen P. Environmental influences on food choice, physical activity and energy balance. Physiol Behav 2005;86(5):603-13.

12. Wang MC, Kim S, Gonzalez AA, et al. Socioeconomic and food-related physical characteristics of the neighbourhood environment are associated with body mass index. J Epidemiol Community Health 2007;61(6):491-8.

13. Schneider S, Gruber J. Neighbourhood deprivation and outlet density for tobacco, alcohol and fast food: first hints of obesogenic and addictive environments in Germany. Public Health Nutr 2013;16(7):1168-77.

14. Gary-Webb TL, Baptiste-Roberts K, Pham L, et al. Neighborhood socioeconomic status, depression, and health status in the Look AHEAD (Action for Health in Diabetes) study. BMC Public Health 2011;11:349.

15. Townshend T, Lake A. Obesogenic environments: current evidence of the built and food environments. Perspect Public Health 2017;137(1):38-44.

16. Compernolle S, Oppert JM, Mackenbach JD, et al. Mediating role of energy-balance related behaviors in the association of neighborhood socio-economic status and residential area density with BMI: The SPOTLIGHT study. Prev Med 2016;86:84-91.

17. Cubbin C, Sundquist K, Ahlen H, et al. Neighborhood deprivation and cardiovascular disease risk factors: protective and harmful effects. Scand J Public Health 2006;34(3):228-37.

18. Cassidy-Bushrow AE, Peters RM, Burmeister C, et al. Neighborhood-Level Poverty at Menarche and Prepregnancy Obesity in African-American Women. Journal of pregnancy 2016;2016:4769121.

19. Pearson AL, Bentham G, Day P, et al. Associations between neighbourhood environmental characteristics and obesity and related behaviours among adult New Zealanders. BMC Public Health 2014;14:553.

20. Schüle SA, Von Kries R, Fromme H, et al. Neighbourhood socioeconomic context, individual socioeconomic position, and overweight in young children: A multilevel study in a large German city. BMC Obesity 2016;3(1).

21. Mohammed SH, Birhanu MM, Sissay TA, et al. What does my neighbourhood have to do with my weight? A protocol for systematic review and meta-analysis of the association between neighbourhood socioeconomic status and body weight. BMJ Open 2017;7(9):e017567.

22. Stroup DF, Berlin JA, Morton SC, et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. JAMA 2000;283(15):2008-12.

23. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. J Clin Epidemiol 2009;62(10):1006-12.

24. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. Eur J Epidemiol 2010;25(9):603-5.

25. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med 2002;21(11):1539-58.

26. Mavridis D, Salanti G. How to assess publication bias: funnel plot, trim-and-fill method and selection models. Evid Based Ment Health 2014;17(1):30.

27. Duval S, Tweedie R. Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics 2000;56(2):455-63.

28. Berry TR, Spence JC, Blanchard C, et al. Changes in BMI over 6 years: the role of demographic and neighborhood characteristics. Int J Obes (Lond) 2010;34(8):1275-83.

29. Feng X, Wilson A. Getting Bigger, Quicker? Gendered Socioeconomic Trajectories in Body Mass Index across the Adult Lifecourse: A Longitudinal Study of 21,403 Australians. PLoS One 2015;10(10):e0141499.

30. Ford PB, Dzewaltowski DA. Neighborhood deprivation, supermarket availability, and BMI in low-income women: a multilevel analysis. Journal of community health 2011;36(5):785-96.

31. Gose M, Plachta-Danielzik S, Willie B, et al. Longitudinal influences of neighbourhood built and social environment on children's weight status. Int J Environ Res Public Health 2013;10(10):5083-96.

32. Leal C, Bean K, Thomas F, et al. Are associations between neighborhood socioeconomic characteristics and body mass index or waist circumference based on model extrapolations? Epidemiology 2011;22(5):694-703.

33. Oliver LN, Hayes MV. Effects of neighbourhood income on reported body mass index: an eight year longitudinal study of Canadian children. BMC Public Health 2008;8:16.

34. Laraia BA, Karter AJ, Warton EM, et al. Place matters: Neighborhood deprivation and cardiometabolic risk factors in the Diabetes Study of Northern California (DISTANCE). Social Science and Medicine 2012;74(7):1082-90.

35. Elfassy T, Yi SS, Llabre MM, et al. Neighbourhood socioeconomic status and cross-sectional associations with obesity and urinary biomarkers of diet among New York City adults: the heart follow-up study. BMJ Open 2017;7(12):e018566.

36. Feng X, Wilson A. Neighbourhood socioeconomic inequality and gender differences in body mass index: The role of unhealthy behaviours. Preventive Medicine 2017;101:171-77.

37. Schüle SA, Fromme H, Bolte G. Built and socioeconomic neighbourhood environments and overweight in preschool aged children. A multilevel study to disentangle individual and contextual relationships. Environmental Research 2016;150:328-36.

38. Alvarado SE. Neighborhood disadvantage and obesity across childhood and adolescence: Evidence from the NLSY children and young adults cohort (1986-2010). Social science research 2016;57:80-98.

39. Coogan PF, Cozier YC, Krishnan S, et al. Neighborhood socioeconomic status in relation to 10-year weight gain in the black women's health study. Obesity 2010;18(10):2064-65.

40. Li X, Memarian E, Sundquist J, et al. Neighbourhood deprivation, individual-level familial and socio-demographic factors and diagnosed childhood obesity: a nationwide multilevel study from Sweden. Obes Facts 2014;7(4):253-63.

41. Oliver LN, Hayes MV. Neighbourhood socio-economic status and the prevalence of overweight Canadian children and youth. Can J Public Health 2005;96(6):415-20.

42. Sellstrom E, Arnoldsson G, Alricsson M, et al. Obesity prevalence in a cohort of women in early pregnancy from a neighbourhood perspective. BMC Pregnancy Childbirth 2009;9:37.

43. Chetty R, Hendren N, Katz LF. The Effects of Exposure to Better Neighborhoods on Children: New Evidence from the Moving to Opportunity Experiment. Am Econ Rev 2016;106(4):855-902.

44. Ellaway A, Benzeval M, Green M, et al. "Getting sicker quicker": does living in a more deprived neighbourhood mean your health deteriorates faster? Health Place 2012;18(2):132-7.

45. Altman DG, Royston P. The cost of dichotomising continuous variables. Bmj 2006;332(7549):1080.

46. Cohen J. The cost of dichotomization. Applied psychological measurement 1983;7(3):249-53.

Figures

Figure 1: PRISMA flow diagram.

Figure 2: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with overweight [overweight versus not overweight].

Figure 3: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with obesity [obese versus not obese].

Figure 4: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with obesity [obese versus not obese], by subgroups.

Figure 5: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index.

Figure 6: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index, by subgroups.

Figure 7: Funnel plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index.

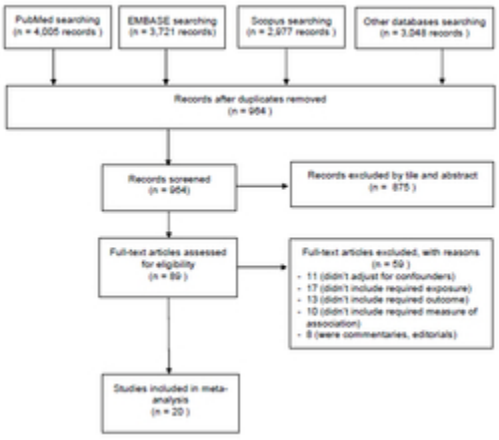

Figure 1: PRISMA flow diagram.

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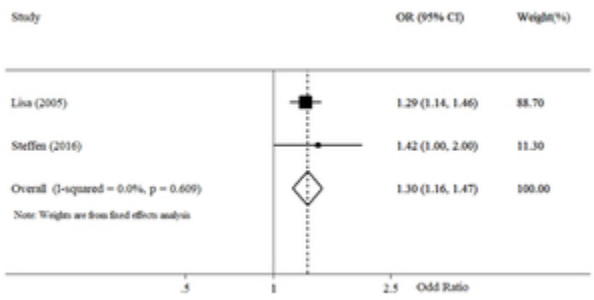

Figure 2: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with overweight [overweight versus not overweight].

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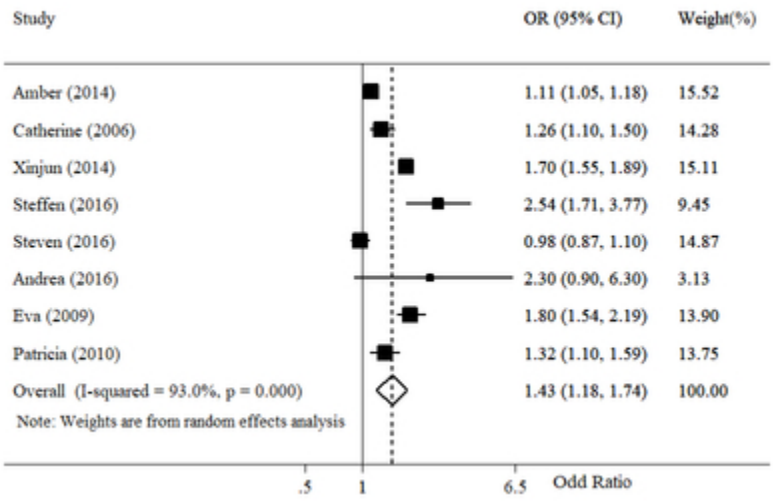

Figure 3: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with obesity [obese versus not obese].

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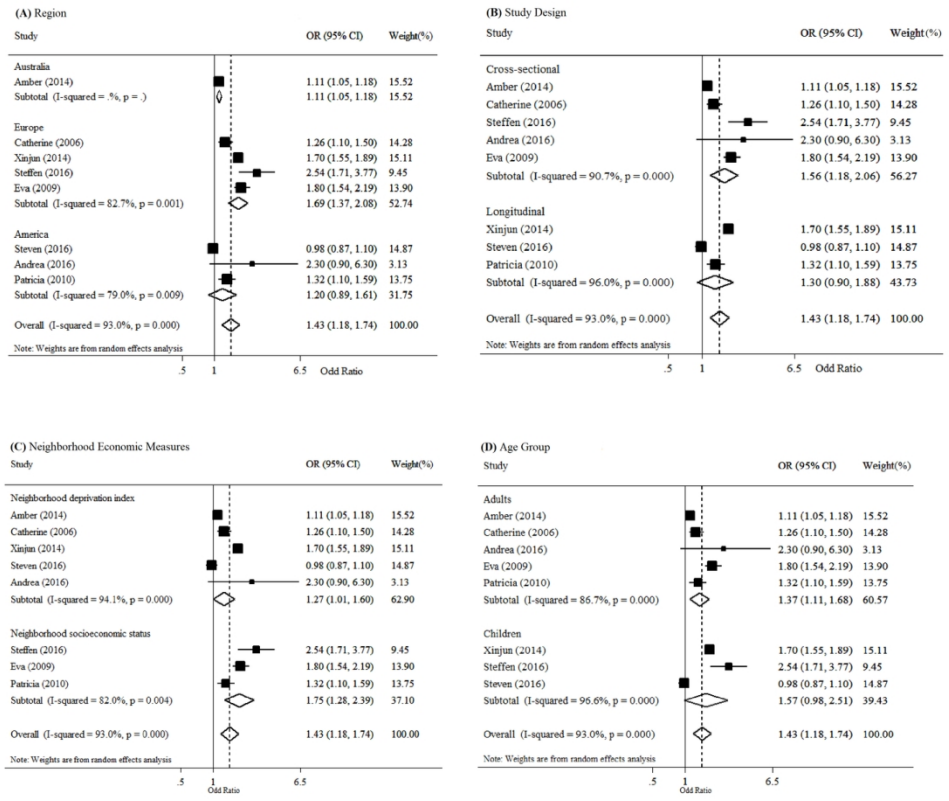

Figure 4: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with obesity [obese versus not obese], by subgroups.

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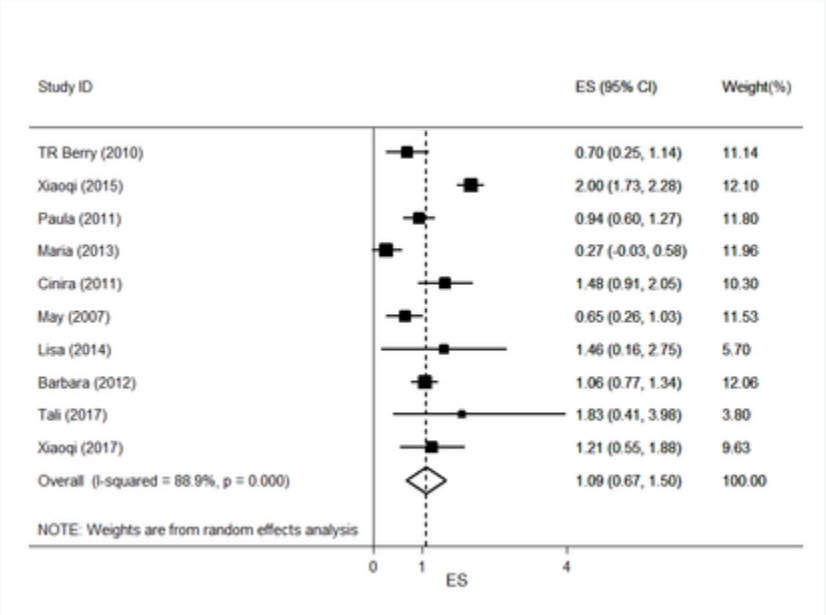

Figure 5: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index.

35x26mm (300 x 300 DPI)

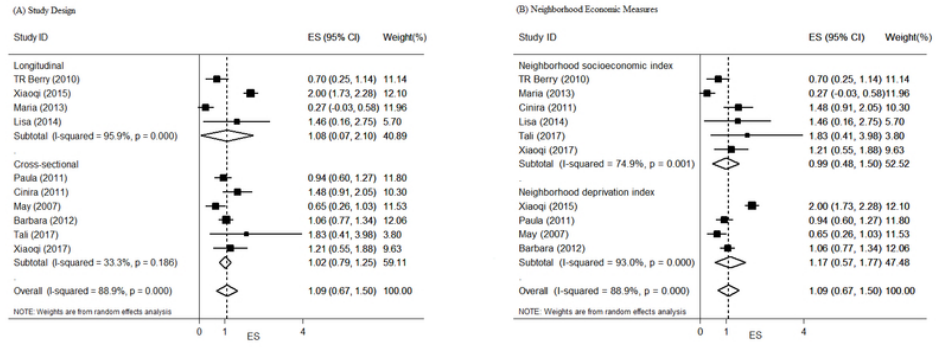

Figure 6: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index, by subgroups.

71x28mm (300 x 300 DPI)

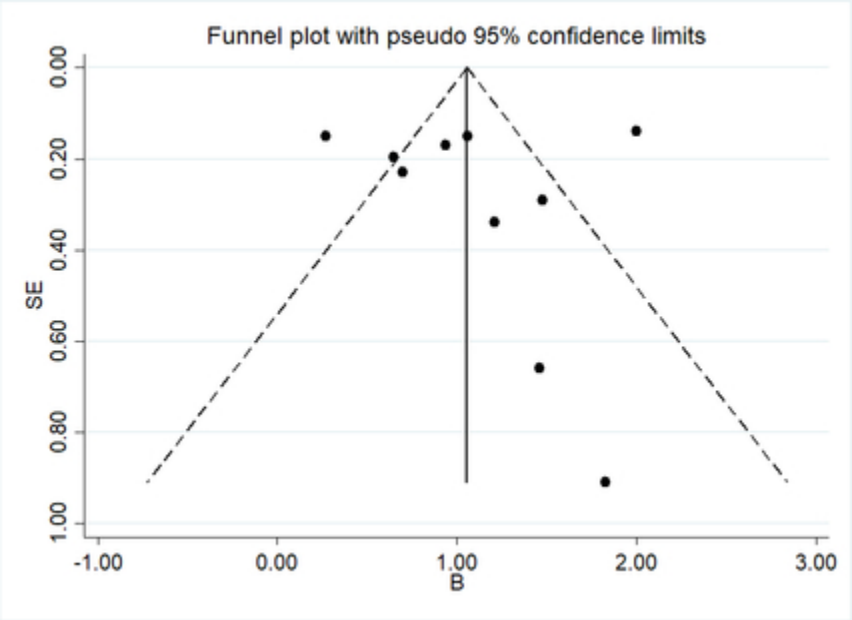

Figure 7: Funnel plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index.

36x26mm (300 x 300 DPI)

PubMed Search strategy

Search	Query	Hits*
#1	(((((((Body Weight[MeSH Terms]) OR Body Mass Index[MeSH Terms]) OR Body weight[Title/Abstract]) OR Weight[Title/Abstract]) OR Obesity[Title/Abstract]) OR Overweight[Title/Abstract]) OR Over-weight[Title/Abstract]) OR BMI[Title/Abstract]	1049827
#2	((((((((((((Residence Characteristics/statistics and numerical data[MeSH Terms]))) OR Residence Characteristics/standards[MeSH Terms]) OR Residence Characteristics/economics[MeSH Terms]) OR Poverty Areas[MeSH Terms]) OR neighborhood socioeconomic*[Title/Abstract]) OR neighbourhood socioeconomic *[Title/Abstract]) OR neighborhood-level socioeconomic*[Title/Abstract]) OR neighbourhood-level socioeconomic*[Title/Abstract]) OR neighborhood socio-economic*[Title/Abstract]) OR neighbourhood socio-economic *[Title/Abstract]) OR neighborhood-level socio-economic*[Title/Abstract]) OR neighbourhood-level socio-economic*[Title/Abstract]	15170
#3	#1 AND #2	4005

*= *Date of search: June 15, 2018*

PRISMA Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4-5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	4-5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5-6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	5-6
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	5-6
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	6-7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	6

PRISMA Checklist

Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (I^2) for each meta-analysis.	6

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	6-7
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	6-7
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7-8
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7-8
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	8
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	7-8
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	7-8
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	8-9
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	8-9
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	9-11
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	11
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	11
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	12

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097.

PRISMA Checklist

doi:10.1371/journal.pmed1000097

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BMJ Open

Neighborhood socioeconomic status and overweight/obesity: a systematic review and meta-analysis of epidemiological studies

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-028238.R2
Article Type:	Original research
Date Submitted by the Author:	02-Oct-2019
Complete List of Authors:	Mohammed, Shimels Hussien; Tehran University of Medical Sciences, Department of Community Nutrition, School of Nutritional Sciences and Dietetics Habtewold, Tesfa; University of Groningen, Epidemiology; Debre Berhan University, Nursing Birhanu, Mulugeta ; Monash University, Department of Medicine, School of Clinical Sciences at Monash Health Sissay, Tesfamichael Awoke ; Addis Ababa University, Department of Public Health, School of Public Health Tegegne, Balewgizie; University of Groningen, Department of Epidemiology, University Medical Center Groningen Abuzerr, Samer; Tehran University of Medical Sciences, Department of Environmental Health Engineering, Faculty of Public Health Esmaillzadeh, Ahmad; Tehran University of Medical Sciences; Tehran University of Medical Sciences, Obesity and Eating Habits Research Center, Endocrinology and Metabolism Molecular Cellular Sciences Institute,
Primary Subject Heading:	Nutrition and metabolism
Secondary Subject Heading:	Epidemiology, Public health
Keywords:	Obesity, Overweight, Body mass index, Neighborhood, Meta-analysis

Neighborhood socioeconomic status and overweight/obesity: a systematic review and meta-analysis of epidemiological studies

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Word count: 3,971

Abstract

Objective: Low neighborhood socioeconomic status (NSES) has been linked to a higher risk of overweight/obesity, irrespective of the individual's own socioeconomic status. No meta-analysis study has been done on the association. Thus, this study was done to synthesize the existing evidence on the association of NSES with overweight, obesity, and body mass index (BMI).

Design: Systematic review and meta-analysis.

Data sources: PubMed, Embase, Scopus, Cochrane Library, Web of Sciences, and Google Scholar databases were searched for articles published until September 25, 2019.

Eligibility criteria: Epidemiological studies, both longitudinal and cross-sectional ones, which examined the link of NSES to overweight, obesity, or BMI were included.

Data extraction and synthesis: Data extraction was done by two reviewers, working independently. The methodological quality of included studies was assessed using the Newcastle-Ottawa Scale for observational studies. The summary estimates of the relationships of NSES with overweight, obesity, and BMI statuses were calculated with random-effects meta-analysis models. Heterogeneity was assessed by Cochran's Q and I^2-statistics. Subgroup analyses were done by age categories, continents, study designs, and NSES measures. Publication bias was assessed by visual inspection of funnel plots and Egger's regression test.

Result: A total of 21 observational studies, covering 1 244 438 individuals, were included in this meta-analysis. Low NSES, compared to high NSES, was found to be associated with a 31% higher odds of overweight [pooled OR=1.31, 95% confidence interval (CI)=1.16-1.47, P<0.001], a 45% higher odds of obesity (pooled OR=1.45, 95%CI=1.21-1.74, P<0.001), and a 1.09 Kg/m^2 increase in mean BMI (pooled Beta=1.09, 95%CI=0.67-1.50, P<0.001).

Conclusion: NSES disparity might be contributing to the burden of overweight/obesity. Further studies are warranted, including whether addressing NSES disparity could reduce the risk of overweight/obesity.

PROSPERO Registration: CRD42017063889

Keywords: Neighborhood socioeconomic status, Obesogenic environment, Overweight, Obesity, Meta-analysis

Strengths and limitations

- This is the first meta-analysis study on the association of NSES with overweight/obesity.

- The report is based on a large number of studies, covering over a million individuals, which improves the representativeness of the sample.
- The studies included in this work are observational in design, precluding making causal inference.
- The study shares the limitations of ecological studies.
- All studies were conducted in high-income countries, which limits the generalizability of the findings to other set-ups.

Introduction

Obesity remains a major public health problem globally. While the current level of obesity has already posed a significant burden to the health system, the problem is still on the rise and causing more negative consequences at both individual and society levels.[1] Worldwide, 39% of adults were estimated to be overweight in 2016. In the same year, 13% of adults were estimated to be obese; almost triple of the figure in 1975.[1] The World Health Organization (WHO) has prioritized the prevention and control of obesity as a central public health agenda and recommends nations to make a substantial improvement with regard to the current trend of obesity.[2] However, the global progress to curb the rising overweight/obesity burden has been slow and frustrating, with each consecutive generation developing overweight/obesity at early ages and higher rates.[3 4]

Overweight/obesity is a multi-causal problem, with risk factors originating from various levels. It often arises from a complex interplay of individual, community, social, and environmental factors. Ecological models of obesity causation have shown that the risk factors of overweight/obesity often interact with each other and might be of direct or indirect influences on the weight status of individuals.[5-7] The main direct determinants are often unhealthy dietary

pattern and insufficient physical activity, resulting in a positive energy balance and consequently high adipose tissue accumulation.[8 9] The environment in which individuals live has a strong influence on one's choice and adoption of health-enhancing behaviors.[6 7 10 11] For example, residence in neighborhoods of low socioeconomic status (SES) has been linked to a higher risk of overweight/obesity, irrespective of individual-level SES.[12] There are various mechanisms through which neighborhood's socioeconomic status (NSES) could influence residents' weight status. One of the most frequently mentioned mechanisms is the 'obesogenic environment' hypothesis that low SES neighborhoods promote an unhealthy dietary practice and sedentary lifestyle.[12 13] In low SES neighborhoods, health-enhancing facilities are often limited. However, energy-dense food items, alcohol, and drug are often more readily available in low SES neighborhoods.[13 14] Another potential, but not a thoroughly examined mechanism, is the 'stressful environment' hypothesis that stressful area might increase the risk of overweight/obesity.[14] Low SES neighborhoods expose residents to more psychosocial stressors and higher risk of depression.[14-16] Depressed individuals, compared to non-depressed, are more likely to adopt an unhealthy lifestyle, like unhealthy dietary practice and inadequate physical exercise, which might result in a higher risk of obesity.[14 17] Besides, in low SES neighborhoods, streets walkability and safety might be compromised; thus, limiting the residents' movement.[11 16] A multinational study in Europe showed that physical inactivity and unhealthy eating jointly accounted for almost a fifth of the association between NSES and body mass index (BMI).[18]

There are a number of empirical studies done on the link of NSES to overweight, obesity, and BMI. The studies were, however, inconsistent in their findings. Some studies reported a null or weak association,[19 20] while other studies reported a strong association between NSES and

overweight/obesity.[21 22] To date, there is no systematic review and meta-analysis report on the association of NSES with overweight, obesity or BMI. Thus, this study was done to provide summary estimates on the link of NSES to overweight, obesity, and BMI. The findings would contribute to filling the gap in the literature and also facilitate evidence-based decision making as there is a better recognition of systematic review and meta-analysis findings in policy and decision making processes.

Methods

This systematic review and meta-analysis work was conducted according to a priori published study protocol[23] and following the recommendations of the Meta-analysis of Observational Studies in Epidemiology (MOOSE)[24] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[25] guidelines. The review protocol was also registered with the International Prospective Register of Systematic Reviews, registration number CRD42017063889.

Literature search

Embase, PubMed, Scopus, Web of Sciences, Cochrane Library, and Google Scholar databases were searched for studies published until September 25, 2019. The search terms were 'neighborhood socioeconomic status', 'neighborhood socioeconomic condition', 'neighborhood socioeconomic index', 'neighborhood deprivation index', 'neighborhood poverty index', 'area deprivation', 'index of multiple deprivation', 'obesity', 'overweight', 'body mass index', 'weight', and 'central obesity'. A sample of the search strategy, PubMed search strategy, developed

using a combination of MeSH terms and free texts is presented (supplementary file 1). The PubMed search strategy was further adapted to the other databases. Additionally, hand searching of articles was done using the reference lists of the eligible studies and the 'cited by' function of PubMed. We aimed to include both observational and interventional studies (cross-sectional, case-control, cohort, longitudinal, and randomized control studies). The literature search was not restricted by sex, age, or geographic location.

Study eligibility criteria

Articles found by the literature search were assessed for whether they fulfilled the predefined inclusion criteria of the study. The outcome variables of interest for this study were BMI (in Kg/m^2 and on a continuous scale), overweight, and obesity. The exposure variable of interest was NSES (measured by composite index). There is neither a uniform nor a standardized approach of NSES measurement. However, in the existing literature, NSES has been often considered as a composite index, developed based on the results of principal component analyses of variables with the potential to indicate neighborhoods' economic conditions. The list of variables often used in the construction of NSES index includes the proportion of households owned by residents, the proportion of employed residents, the value of assets in the area, property ownership by residents, availability of health-promoting amenities, and the literacy rate of the area. However, the specific set of variables used in the development of NSES indices often vary from study to study depending on many contextual and statistical factors, like data availability and the result of the principal component analysis. One of the criteria for including a study in this work was that the measurement of NSES in the study should be by composite indices like neighborhood economic status indices (NSESI), neighborhood deprivation indices

(NDI), index of multiple deprivations (IMD), or neighborhood economic hardship- indices (NEDI). The commonly used indices are NSESI and NDI, both of which could be used to rank neighborhoods into different SES categories, like low (deprived), middle, and high (better-off) SES categories. Articles were excluded for any one of the following conditions: (1) animal studies, (2) study which focused on the physical, policy, or social aspects of the environment, (3) language other than English, (4) citations without full text, (5) studies in which the outcome measure was not overweight, obesity or BMI, (6) studies in which participants' nutritional status was not defined by BMI, (7) studies in which only crude (unadjusted) estimates were reported, and (8) qualitative studies, book chapters, symposium and conference proceedings, essays, commentaries, editorials, and case reports.

Study screening and data extraction

The results of the database search were exported to EndNote X8 software to remove duplicates and manage the screening processes. Then, the titles and abstracts of the retrieved studies were assessed by two reviewers (SHM, TDH), working independently and in duplicate, to determine their eligibility for full-text reviewing. The full text reviewing was done by SHM and TDH, with disagreement resolved by consensus. The process of article screening and selection is presented in Figure 1. SHM extracted the data, double-checked by TDH. The data extracted from included studies were (1) study identification (first author, year of publication, and title), (2) study characteristics (country, study design, sample size, and follow-up period for longitudinal studies), (3) study participant's characteristics (sex, proportion of men, and mean age), (4) NSES assessment method, (5) outcome assessment method, (6) measure of association and reported estimate, and (7) variables used for adjustment. The predefined measures of

association were beta (β) of BMI, relative risk (RR), or odds ratio (OR). The beta (β) of BMI refers to the mean difference in BMI of individuals living in low and high SES neighborhoods. The OR refers to the odds of overweight or obesity among individuals living in low SES neighborhoods, compared to individuals living in high SES neighborhoods. When a study reported two or more estimates on the same issue, we took the estimate that was adjusted for more variables and when a study reported multiple NSES comparisons, we took the estimate that compared the highest and the lowest NSES categories.

Study quality assessment

The methodological quality of each of the included studies was assessed using the Newcastle-Ottawa Scale (NOS) for grading the quality of observational studies.[26] The tool uses three main parameters: (1) selection (assesses sample representativeness, sample size, non-response handling, and exposure ascertainment), (2) comparability (assesses comparability of study groups and confounding control), and (3) outcome (assesses ascertainment of outcome and appropriateness of statistical tests). The quality grading was done out of 9, with scores from 0 to 3 indicating low quality, 4 to 6 medium quality, and 7 to 9 high quality. The ratings for each study were compared between the two evaluators (SHM, TDH), with discrepancy resolved by consensus.

Statistical analysis

Separate meta-analyses were done for each of the three outcome measures: overweight, obesity, and BMI. OR was used to pool the estimate of studies that reported on NSES-Overweight and NSES-Obesity associations, representing the odds of overweight or obesity among individuals living in low SES neighborhoods, compared to individuals living in high SES

neighborhoods. Beta (β) values from linear regression analyses, representing the mean increase in BMI due to change in NSES from the highest to the lowest category, were used to pool the estimates of studies that used BMI, on a continuous scale, as an outcome measure. For all estimates, if P-values were reported as P<0.001 with no 95% confidence interval (CI) or standard error (SE), we assumed P=0.001 in calculating the corresponding 95%CI and SE.

Heterogeneity among the studies was assessed by Cochran's Q and I^2-statistics, which quantify the proportion of variance attributable to between-studies heterogeneity. A non-substantial level of statistical heterogeneity was assumed when P<0.1 or I^2<50%.[27] Sources of heterogeneity were assessed by conducting subgroup analyses using the predefined variables outlined in the study protocol,[23] which were age category (adults versus children), study design (cross-sectional versus longitudinal), region (continent), and NSES measures. Due to a persistently high level of heterogeneity even after subgroup analyses, we calculated the summary estimates with random-effects model, which accounts for both within and between studies variations. Publication bias was assessed by both visual inspection of funnel plots and Egger's regression test, unless the number of studies was inadequate and under-powered any of the statistical methods for assessing publication bias. A minimum of ten studies is needed to ensure adequate power and assess publication bias.[28] According to Egger's test, publication bias is assumed at P<0.1.[28 29] For estimates with evidence of publication bias, we aimed to do adjustment following the Trim and Fill method[28 29] and provide both publication bias-adjusted and unadjusted pooled estimates. To evaluate the influence of each study on the pooled estimate, we conducted sensitivity analyses using the leave-one-out and analyze the rest method. For this purpose, we specifically used the *'metaninf'* command of Stata, which provides a table and a graph of re-

estimated results, omitting studies turn by turn. For a study to be excessively influential, the point estimate of the meta-analysis result, done with the omission of the study, should lie outside the 95% CI of the combined meta-analysis estimate, done with the inclusion of all studies.[30] All statistical analyses were done using Stata software (version 15).

Patient and public involvement

This work was based on extracting data from published studies. There was no patient and public involvement in the development of the research question, design, outcome measures, study implementation, and result communication.

Result

Search result and study characteristics

The search strategy generated a total of 6 671 studies. Screening the title and abstract of these studies resulted in 94 studies eligible for full-text review. Reviewing the full text of the 94 studies, 18 studies were found eligible for inclusion. Through hand searching the references of the included studies and the 'cited by' function of PubMed, three additional articles were identified. The flowchart of the screening and selection process is shown in Figure 1. The main characteristics of the 21 included studies[12 19-22 31-46] are shown in Table 1. The sample size of the studies ranged from 144 to 948 062 individuals, providing a total of 1 244 438 unique individuals, of whom 45% were males and 55% females. The studies were published from 2005 to 2018 and included both adults and children. The majority of the studies, 14/21 (67%), were cross-sectional in design. The remaining 7 (33%) were longitudinal (cohort) studies. All studies

were conducted in high-income countries: 7 in USA, 3 in Canada, 3 in Germany, 2 in Australia, 3 in Sweden, 1 in France, 1 in UK, and 1 in New Zealand.

1

Table 1: General characteristics included studies.

First author (year)	Country	Study design	Follow-up (years)	Sample (n)	Mean age	Men (%)	Population	NSES‡ measure	Weight measure	Adjustment	NOS Scale
Amber (2014)[21]	New Zealand	CS	NA	12 488	47.00	53.00	Adults	NDI	Obesity	Age, sex, ethnicity, economic living standard index, individual-level deprivation, highest educational qualification, household composition, smoking status, alcohol consumption	8
Steffen (2016)[40]	Germany	CS	NA	3 499	6.00	53.00	Children	NSESI	Obesity	Birth weight, BMI of the mother, parental education, parental working status, household income, household crowding	9
Catherine (2006)[19]	Sweden	CS	NA	18 081	44.60	49.20	Adults	NDI	Obesity	Age, gender, marital status, immigration status, urbanization	6
Steven (2016)[41]	USA	LS	24	11 499	10.31	51.00	Children	NDI	Obesity	Age, sex	7
Patricia (2010)[42]	USA	LS	10	48 359	NA	0.00	Adults	NSESI	Obesity	Age, family income, marital status, exercise, energy intake, smoking	8
Andrea (2016)[20]	USA	CS	NA	144	26.40	100.00	Adults	NDI	Obesity	Maternal age, marital status, maternal education, parity	
Xinjun (2014)[43]	Sweden	LS	10	948 062	8.60	51.30	Children	NDI	Obesity	Age, family (income, history of obesity & diabetes), personal history of (chronic obstructive pulmonary disease, alcoholism & diabetes)	9
Eva (2009)[45]	Sweden	CS	NA	94 323	31.40	100.00	Adults	NSESI	Obesity	Age, sex, individual income, education status	9
Steffen (2016)[22]	Germany	CS	NA	3 499	6.00	53.00	Children	NSESI	Overweight	Birth weight, BMI of the mother, parental education, parental working status, household income, household crowding	7
Lisa (2005)[44]	Canada	CS	NA	11 455	11.80	50.80	Children	NDI	Overweight	Age, gender, family income, education level	8
TR Berry (2010)[31]	Canada	LS	6	500	42.81	52.00	Adults	NSESI	BMI	Age, sex	8
Xiaoqi (2015)[32]	Australia	LS	6	18 341	46.60	47.00	Adults	NDI	BMI	Age, sex, number of children in the household, household education status, household unemployment, annual household income	9
Paula (2011)[33]	USA	CS	NA	21 166	24.94	0.00	Adults	NDI	BMI	Tract supermarkets, tract small grocery stores, tract convenience stores, ethnicity, education, annual income statuses	8
Maria (2013)[34]	Germany	LS	4	485	5.81	51.72	Children	NSESI	BMI	Street type, perceived frequency of passing trucks and buses, street walkability	7

Cinira (2011)[35]	France	CS	NA	7 230	46.80	0.00	Adults	NSESI	BMI	Age, country human development index, individual education level, occupation, financial strain, cultural entertainments, health-related external locus of control, propensity to keep healthy resolutions	8
May (2007)[12]	USA	CS	NA	7 595	52.81	49.25	Adult	NDI	BMI	Age, gender, ethnicity, individual-level socioeconomic status, smoking, physical activity, nutrition knowledge	8
Lisa (2014)[36]	Canada	LS	8	2 152	2.48	50.44	Children	NSESI	BMI	Age, sex, income, education, family structure	8
Barbara (2012)[37]	USA	CS	NA	19 804	48.30	51.20	Adults	NDI	BMI	Race, sex, age, income, education level, marital status, nativity, individual socioeconomic status	8
Tali (2017)[38]	USA	CS	NA	1 645	49.00	42.00	Adults	NSESI	BMI	Age, race, education, poverty, employment status, physical activity	9
Xiaoqi (2017)[39]	Australia	CS	NA	10 281	44.70	47.60	Adults	NSESI	BMI	Gender, age	6
Walker (2018)[46]	UK	CS	NA	3 830	29.6	0.00	Adults	MDI	Obesity	Age, ethnicity, parity, smoking	9

1 LS=Longitudinal, CS=Cross-sectional, NA=Not applicable, NSES=Neighborhood socioeconomic status, NDI=Neighborhood deprivation index, BMI=Body mass index, NOS=Newcastle
2 Ottawa Scale, USA=United States of America, UK=United Kingdom, MDI=Multiple deprivation index

Association of NSES with overweight

We found two studies that examined the link of NSES to overweight, as defined by 25≤BMI<25 kg/m^2. The summary odds of being overweight, compared to being not overweight (BMI<25 kg/m^2), was 30% higher in individuals living in low SES neighborhoods, compared to that of individuals living in high SES neighborhoods (pooled OR=1.30, 95%CI=1.16-1.47, P<0.001). There was no evidence of significant heterogeneity (I^2=0.00%, P=0.609). Figure 2 presents the result of the meta-analysis of the NSES-overweight association.

Association of NSES with Obesity

We found nine studies that examined the association of NSES with obesity, as defined by BMI≥30 kg/m^2. The odds of being obese, compared to being non-obese, was 43% higher in individuals living in low SES neighborhoods, compared to that of individuals living in high SES neighborhoods (pooled OR=1.45, 95%CI=1.21-1.74, P<0.001). Figure 3 shows the forest plot and the summary estimate of the meta-analysis of the NSES-obesity association done with all studies included. There was a high level of heterogeneity among the studies (I^2=93.00%, P<0.001). We explored the sources of the heterogeneity by doing subgroup analyses. The subgroup-specific summary estimates with their corresponding heterogeneity levels are shown in Figure 4. Across the three continents where the studies were done (Australia, America, and Europe), NSES maintained a significant association with obesity (P<0.05). In children, residence in low SES neighborhoods was associated with a 1.57 times higher odds of obesity, compared to residence in high SES neighborhoods. However, the association was not statistically significant, albeit largely towards indicating the existence of a significant association (pooled OR=1.57, 95%CI=0.98-2.51). In adults, low NSES was associated a significantly higher

odds of obesity, such that the odds of obesity was 1.40 times higher in adults living in low SES neighborhoods, compared to that of adults living in high SES neighborhoods (pooled OR=1.40, 95%CI=1.15-1.69). In terms of study design, NSES was significantly linked to obesity in cross-sectional studies, but not in longitudinal studies. It was not possible to assess publication bias for the NSES-obesity association as there was an inadequate number of studies, under-powering any of the statistical methods for assessing publication bias. The existing statistical tests require a minimum of ten studies to have adequate power to assess publication bias.[28] To evaluate the influence of each study on the summary estimate, we conducted sensitivity analyses (Table 2). Overall, no study notably changed of the direction as well as the magnitude the NSES-Obesity association, with the summary OR ranging from the lowest 1.32 (95%CI=1.13-1.50) after excluding Xinjun et al.[43] to the highest 1.51 (95%CI=1.24-1.77) after excluding Steven et al.[41]

Table 2: Sensitivity analysis of studies on the association of neighborhood socioeconomic status with obesity.

Study omitted	Pooled OR	95% CI
Amber (2014)[21]	1.50	1.20-1.80
Catherine (2006)[19]	1.44	1.19-1.70
Xinjun (2014)[43]	1.32	1.13-1.50
Steffen (2016)[40]	1.37	1.15-1.58
Steven (2016)[41]	1.51	1.24-1.77
Andrea (2016)[20]	1.40	1.19-1.62
Eva (2009)[45]	1.35	1.13-1.56
Patricia (2010)[42]	1.43	1.19-1.67

Walker (2018)[46]	1.39	1.17-1.62

OR=Odds ratio, CI=Confidence interval

Association of NSES with BMI

Ten of the 21 studies included in this work examined the relation of NSES with BMI, as a continuous variable. Overall, the summary estimate showed that NSES was significantly associated with BMI. The BMI of individuals living in low SES neighborhoods was higher by a mean of 1.09 kg/m^2, compared to the BMI of individuals living in high SES neighborhoods (pooled β=1.09, 95%CI=0.67-1.50, P<0.001). Figure 5 shows the summary estimate of the association of NSES with BMI, calculated with random-effects model. There was a significant level of heterogeneity (I^2<0.001). Thus, subgroup analyses were conducted by the designs of the studies (cross-sectional versus longitudinal) and the methods of the NSES measures. In all subgroups, BMI was significantly higher in low SES neighborhoods than in high SES neighborhoods. Details of the results of the subgroup analyses by study design and NSES measurement methods are presented in Figure 6. The result of the Egger's regression test did not indicate the presence of a significant level of publication bias (P=0.903). The funnel plot of the NSES-BMI studies is shown in Figure 7. The result of the sensitivity analyses of the studies on the NSES-BMI association is shown in Table 3. Overall, no study notably influenced the direction as well as the strength of the NSES-BMI association, with the pooled β ranging from the lowest 0.90 (95%CI=0.62-1.19) after excluding Xiaoqi (2015)[32] to the highest 1.19 (95%CI=0.80-1.58) after excluding Maria (2013)[34].

Table 3: Sensitivity analysis of studies on the association of neighborhood socioeconomic status with body mass index.

Study omitted	Pooled Beta	95% CI
TR Berry (2010)[31]	1.14	0.68-1.60
Xiaoqi (2015)[32]	0.90	0.62-1.19
Paula (2011)[33]	1.11	0.63-1.60
Maria (2013)[34]	1.19	0.80-1.58
Cinira (2011)[35]	1.04	0.59-1.50
May (2007)12	1.15	0.68-1.61
Lisa (2014)[36]	1.07	0.63-1.50
Barbara (2012)[37]	1.10	0.60-1.60
Tali (2017)[38]	1.06	0.63-1.49
Xiaoqi (2017)[39]	1.08	0.62-1.53

CI=Confidence interval

Discussion

This study was done to pool the existing empirical evidence on the link of NSES to overweight, obesity, and BMI. Overall, NSES was found to be significantly associated with the three outcome measures, such that low NSES was significantly linked to high odds of overweight, obesity, and a higher mean BMI.

The findings of this work were consistent with the reports of previous studies that reported higher odds of overweight/obesity as well as other poor health outcomes in individuals living in

low SES neighborhoods than in individuals living in high SES neighborhoods.[22 43 44] The influence of neighborhood deprivation is not limited to only body weight. It has also been linked to various poor behavioral and health outcomes like drug abuse, cardiovascular diseases, and poor mental health.[15 47] Thus, improving NSES has been recommended as a potential strategy for prevention and control of the current obesity epidemics and other chronic illnesses.[15 47] The mechanisms through which NSES contributes to the development of overweight/obesity have not been thoroughly documented. Despite the ongoing debate on which of the mediating factors deserves the most responsibility for the link of NSES to body weight, most factors are, however, believed to influence weight mainly through influencing the energy balance, i.e. the balance of calorie intake and loss.[9-11] Low SES neighborhoods have been associated with a high availability of energy-dense and junk food outlets, but a low availability of fruit and vegetable outlets and limited sporting facilities. Low SES neighborhoods have also been related to a higher risk of depression, which could subsequently lead to a higher risk of overweight/obesity.[14]

In this work, there was discrepancy in the NSES-Obesity association by study designs, i.e., between cross-sectional and longitudinal studies. A statistically significant NSES-Obesity association was demonstrated in the cross-sectional studies, but not in the longitudinal studies. However, it is worth noting that the NSES-Obesity association was consistently demonstrated across the other subgroup analyses by age (adults versus children), NSES measures (NSESI versus NDI), and outcome measures (overweight versus obesity). The discrepancy by study design was also not observed in the NSES-BMI association, in which NSES demonstrated significant statistical links to BMI in both longitudinal and cross-sectional studies. There are a number of possible reasons that could explain the discrepancy in the NSES-Obesity association

between cross-sectional and longitudinal studies. First, it could be most probably due to the fact that only two longitudinal studies were included in the NSE-Obesity association analysis. Second, there was no uniformity in how confounding was controlled among the included studies, in terms of both the number and the type of variables used for adjustment. This lack of uniformity across the studies in covariates adjustment might in part explain the discrepancy in the NSES-Obesity summary estimates by study designs. Third, it could also be due to the use of a dichotomized outcome variable (obesity), instead of a continuous outcome variable (BMI). Unless it is mandatory, dichotomization of continuous variables is not recommended as it reduces sample power by almost 50% and could result in false no association findings, particularly if the true association is weak.[48 49] In support of this, we observed no discrepancy between cross-sectional and longitudinal studies in all NSES-BMI summary estimates, in which the outcome was BMI on a continuous scale. Fourth, it could be due to the differences in measures of magnitude and associations of events between cross-sectional and longitudinal studies. Classically, cross-sectional studies measure the prevalence of events (which includes both new and old events), but longitudinal studies measure the incidence of events (which includes only new events). In cross-sectional studies, risk could not be directly measured, unlike in longitudinal studies in which it could be directly measured. Besides, reverse causality could not be ruled out in cross-sectional studies.[50] However, as none of the above reasons could definitively explain the NSES-Obesity discrepancy by study design, we recommend further meta-analyses works when more longitudinal or quasi-experimental studies become available.

The finding of this study might indicate the importance of investigating as well as addressing the determinants of overweight/obesity comprehensively, i.e., examining and addressing not only

the proximal behavioral risk factors of obesity but also its underlying environmental and other structural risk factors. However, the existing literature is largely focused on investigating and addressing the individual level behavioral influences of obesity.[7] For example, the evidence is limited about how, and to what extent, neighborhood socioeconomic conditions influence individuals' dietary practice and physical activity level. Whether improving neighborhood economic deprivation could result in the adoption of health-enhancing lifestyle also remains largely unknown. Besides, the existing reports on the link of NSES to an unhealthy weight, including the report of this work, are largely based on observational studies. Thus, further investigations with better designs, like community-based longitudinal studies, are needed to reach into a better conclusion on the relationship. Meanwhile, it might be worthy of considering a comprehensive approach when developing obesity prevention and control strategies, including addressing neighborhood economic disparities. So far, obesity interventions have been primarily focused on providing health information and strategies to address its individual-level determinants. However, unless supported by an enabling environment, the individual level efforts or the provision of health information alone might not lead to the intended result as fast as needed. Thus, the lack of comprehensiveness and integration of interventions might partly explain the current non-promising progress of obesity prevention and control approaches.[4 16] Low SES neighborhoods often lack health-promoting amenities, like sport facilities and fruit/vegetable outlets.[13] We believe that addressing neighborhood deprivation, by availing healthier choices closer and affordable to everyone, might facilitate the adoption of health-enhancing behaviors, thereby reducing the risk of overweight/obesity. However, the proposition needs to be further examined.

Limitations and strengths

This work has many limitations. There was no uniformity among the studies in the way NSES was measured. Though NSES was treated as a composite variable in all included studies, the specific set of variables used to develop the NSES indices varied from one study to another. There was also variation across the studies in terms of the type and number of covariates used for adjustment of the reported estimates. The lack of uniformity in the NSES measures and the covariates adjusted for might have introduced heterogeneity and undermined the comparability of the studies. All studies included in this work were done in high-income countries. The lack of data from low- and middle- income countries would limit the generalizability of the findings. NSES-obesity association would vary by countries' socioeconomic status. In developing countries, due to the traditionally held positive attitude toward overweight, low NSES might be associated with a lower risk of overweight/obesity, unlike the case in high income or developed countries. Therefore, the findings of this work might not be applicable to developing countries. All studies included in this work were observational in design, making casual inference impossible. The possibility of reverse causality could not be ruled out; i.e. instead of high SES neighborhoods promoting healthy weight, it could be possible that individuals with a normal weight are more interested in health and therefore prefer living in high SES neighborhoods. In this meta-analysis, ecological studies were included. Thus, it also shares the limitations of ecological studies. We also did not examine the relation of NSES with waist circumference and waist-to-hip ratio, though they are also measures of adiposity and nutritional status. To the best of our knowledge, this is the first systematic review and meta-analysis study on the link of NSES

to overweight, obesity, and BMI. Thus, it would be contributing to filling the existing gap in the literature. The inclusion of multi-national studies, a large number of study participants, and individuals of all age groups could improve the representativeness of the study.

Conclusion

We found that living in low SES neighborhoods, compared to living in high SES neighborhoods, was associated with higher odds of being overweight and obese as well as a higher mean BMI. Evidence on the association of NSES with weight status is limited in low and middle-income countries. The exact mechanism by which low NSES contributes to an unhealthy weight gain and whether addressing NSES disparity reduces the risk of obesity are largely unclear. Thus, further studies are warranted to better understand how NSES influences weight and whether addressing NSES disparity could reduce the risk of overweight/obesity. Meanwhile, addressing NSES disparity and bringing healthy choices closer and affordable to everyone might be important to curb the current trend of obesity.

Authors' contribution

SHM conceived and lead the study, carried out literature search, performed quality assessment, analyzed the data, and wrote the manuscript. TDH, TAS, MMB, BST, and SA performed literature search, screening, data extraction, and quality assessment as second reviewers. AE supervised the work. All authors read, commented, and approved the final manuscript.

Funding

This research received no specific grant from any funding agency in public, commercial or not-for-profit sectors.

Competing interest

None declared.

Data sharing statement

All the data used are included in the study.

Patient consent

Not required as the study was based on extracting data from published studies.

References

1. World Health Organization. Obesity and overweight fact sheet. 2014 http://www.who.int/mediacentre/factsheets/fs311/en/ (accessed 29 September 2019).

2. Alleyne G, Binagwaho A, Haines A, et al. Embedding non-communicable diseases in the post-2015 development agenda. *Lancet* 2013;381(9866):566-74.

3. Hulsegge G, Picavet HS, Blokstra A, et al. Today's adult generations are less healthy than their predecessors: generation shifts in metabolic risk factors: the Doetinchem Cohort Study. *Eur J Prev Cardiol* 2014;21(9):1134-44.

4. Roberto CA, Swinburn B, Hawkes C, et al. Patchy progress on obesity prevention: emerging examples, entrenched barriers, and new thinking. *Lancet* 2015;385(9985):2400-9.

5. Booth KM, Pinkston MM, Poston WS. Obesity and the built environment. *J Am Diet Assoc* 2005;105(5 Suppl 1):S110-7.

6. Lipek T, Igel U, Gausche R, et al. Obesogenic environments: environmental approaches to obesity prevention. *J Pediatr Endocrinol Metab* 2015;28(5-6):485-95.

7. Papas MA, Alberg AJ, Ewing R, et al. The built environment and obesity. *Epidemiol Rev* 2007;29:129-43.

8. Hall KD, Heymsfield SB, Kemnitz JW, et al. Energy balance and its components: implications for body weight regulation. *Am J Clin Nutr* 2012;95(4):989-94.

9. Hill JO. Understanding and addressing the epidemic of obesity: an energy balance perspective. *Endocr Rev* 2006;27(7):750-61.

10. Cohen DA. Obesity and the built environment: changes in environmental cues cause energy imbalances. *Int J Obes (Lond)* 2008;32 Suppl 7:S137-42.

11. Popkin BM, Duffey K, Gordon-Larsen P. Environmental influences on food choice, physical activity and energy balance. *Physiol Behav* 2005;86(5):603-13.

12. Wang MC, Kim S, Gonzalez AA, et al. Socioeconomic and food-related physical characteristics of the neighbourhood environment are associated with body mass index. *J Epidemiol Community Health* 2007;61(6):491-8.

13. Schneider S, Gruber J. Neighbourhood deprivation and outlet density for tobacco, alcohol and fast food: first hints of obesogenic and addictive environments in Germany. *Public Health Nutr* 2013;16(7):1168-77.

14. Gary-Webb TL, Baptiste-Roberts K, Pham L, et al. Neighborhood socioeconomic status, depression, and health status in the Look AHEAD (Action for Health in Diabetes) study. *BMC Public Health* 2011;11:349.

15. Ellaway A, Benzeval M, Green M, et al. "Getting sicker quicker": does living in a more deprived neighbourhood mean your health deteriorates faster? *Health Place* 2012;18(2):132-7.

16. Townshend T, Lake A. Obesogenic environments: current evidence of the built and food environments. *Perspect Public Health* 2017;137(1):38-44.

17. Luppino FS, de Wit LM, Bouvy PF, et al. Overweight, obesity, and depression: a systematic review and meta-analysis of longitudinal studies. *Archives of general psychiatry* 2010;67(3):220-29.

18. Compernolle S, Oppert JM, Mackenbach JD, et al. Mediating role of energy-balance related behaviors in the association of neighborhood socio-economic status and residential area density with BMI: The SPOTLIGHT study. *Prev Med* 2016;86:84-91.

19. Cubbin C, Sundquist K, Ahlen H, et al. Neighborhood deprivation and cardiovascular disease risk factors: protective and harmful effects. *Scand J Public Health* 2006;34(3):228-37.

20. Cassidy-Bushrow AE, Peters RM, Burmeister C, et al. Neighborhood-Level Poverty at Menarche and Prepregnancy Obesity in African-American Women. *Journal of pregnancy* 2016;2016:4769121.

21. Pearson AL, Bentham G, Day P, et al. Associations between neighbourhood environmental characteristics and obesity and related behaviours among adult New Zealanders. *BMC Public Health* 2014;14:553.

22. Schüle SA, Von Kries R, Fromme H, et al. Neighbourhood socioeconomic context, individual socioeconomic position, and overweight in young children: A multilevel study in a large German city. *BMC Obesity* 2016;3(1).

23. Mohammed SH, Birhanu MM, Sissay TA, et al. What does my neighbourhood have to do with my weight? A protocol for systematic review and meta-analysis of the association between neighbourhood socioeconomic status and body weight. *BMJ Open* 2017;7(9):e017567.

24. Stroup DF, Berlin JA, Morton SC, et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA* 2000;283(15):2008-12.

25. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol* 2009;62(10):1006-12.

26. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol* 2010;25(9):603-5.

27. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med* 2002;21(11):1539-58.

28. Mavridis D, Salanti G. How to assess publication bias: funnel plot, trim-and-fill method and selection models. *Evid Based Ment Health* 2014;17(1):30.

29. Duval S, Tweedie R. Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. *Biometrics* 2000;56(2):455-63.

30. Borenstein M, Hedges LV, Higgins JP, et al. Introduction to meta-analysis: John Wiley & Sons 2011.

31. Berry TR, Spence JC, Blanchard C, et al. Changes in BMI over 6 years: the role of demographic and neighborhood characteristics. *Int J Obes (Lond)* 2010;34(8):1275-83.

32. Feng X, Wilson A. Getting Bigger, Quicker? Gendered Socioeconomic Trajectories in Body Mass Index across the Adult Lifecourse: A Longitudinal Study of 21,403 Australians. *PLoS One* 2015;10(10):e0141499.

33. Ford PB, Dzewaltowski DA. Neighborhood deprivation, supermarket availability, and BMI in low-income women: a multilevel analysis. *Journal of community health* 2011;36(5):785-96.

34. Gose M, Plachta-Danielzik S, Willie B, et al. Longitudinal influences of neighbourhood built and social environment on children's weight status. *Int J Environ Res Public Health* 2013;10(10):5083-96.

35. Leal C, Bean K, Thomas F, et al. Are associations between neighborhood socioeconomic characteristics and body mass index or waist circumference based on model extrapolations? *Epidemiology* 2011;22(5):694-703.

36. Oliver LN, Hayes MV. Effects of neighbourhood income on reported body mass index: an eight year longitudinal study of Canadian children. *BMC Public Health* 2008;8:16.

37. Laraia BA, Karter AJ, Warton EM, et al. Place matters: Neighborhood deprivation and cardiometabolic risk factors in the Diabetes Study of Northern California (DISTANCE). *Social Science and Medicine* 2012;74(7):1082-90.

38. Elfassy T, Yi SS, Llabre MM, et al. Neighbourhood socioeconomic status and cross-sectional associations with obesity and urinary biomarkers of diet among New York City adults: the heart follow-up study. *BMJ Open* 2017;7(12):e018566.

39. Feng X, Wilson A. Neighbourhood socioeconomic inequality and gender differences in body mass index: The role of unhealthy behaviours. *Preventive Medicine* 2017;101:171-77.

40. Schüle SA, Fromme H, Bolte G. Built and socioeconomic neighbourhood environments and overweight in preschool aged children. A multilevel study to disentangle individual and contextual relationships. *Environmental Research* 2016;150:328-36.

41. Alvarado SE. Neighborhood disadvantage and obesity across childhood and adolescence: Evidence from the NLSY children and young adults cohort (1986-2010). *Social science research* 2016;57:80-98.

42. Coogan PF, Cozier YC, Krishnan S, et al. Neighborhood socioeconomic status in relation to 10-year weight gain in the black women's health study. *Obesity* 2010;18(10):2064-65.

43. Li X, Memarian E, Sundquist J, et al. Neighbourhood deprivation, individual-level familial and socio-demographic factors and diagnosed childhood obesity: a nationwide multilevel study from Sweden. *Obes Facts* 2014;7(4):253-63.

44. Oliver LN, Hayes MV. Neighbourhood socio-economic status and the prevalence of overweight Canadian children and youth. *Can J Public Health* 2005;96(6):415-20.

45. Sellstrom E, Arnoldsson G, Alricsson M, et al. Obesity prevalence in a cohort of women in early pregnancy from a neighbourhood perspective. *BMC Pregnancy Childbirth* 2009;9:37.

46. Walker IV, Cresswell JA. Multiple deprivation and other risk factors for maternal obesity in Portsmouth, UK. *J Public Health (Oxf)* 2019;41(2):278-86.

47. Chetty R, Hendren N, Katz LF. The Effects of Exposure to Better Neighborhoods on Children: New Evidence from the Moving to Opportunity Experiment. *Am Econ Rev* 2016;106(4):855-902.

48. Altman DG, Royston P. The cost of dichotomising continuous variables. *Bmj* 2006;332(7549):1080.

49. Cohen J. The cost of dichotomization. *Applied psychological measurement* 1983;7(3):249-53.

50. Rothman KJ, Greenland S, Lash TL. Modern epidemiology: Wolters Kluwer Health/Lippincott Williams & Wilkins Philadelphia 2008.

Figure 1: PRISMA flow diagram.

Figure 2: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with overweight [overweight versus not overweight].

Figure 3: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with obesity [obese versus not obese].

Figure 4: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with obesity [obese versus not obese], by subgroups.

Figure 5: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index.

Figure 6: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index, by subgroups.

Figure 7: Funnel plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index.

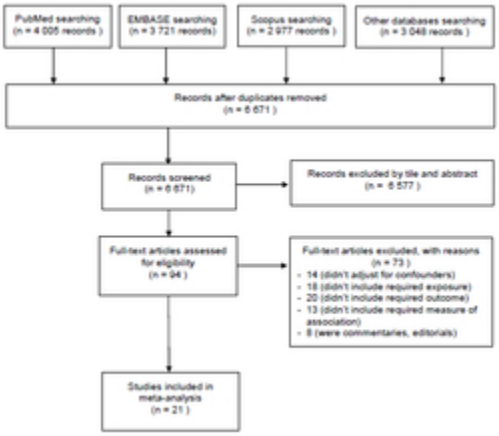

Figure 1: PRISMA flow diagram.

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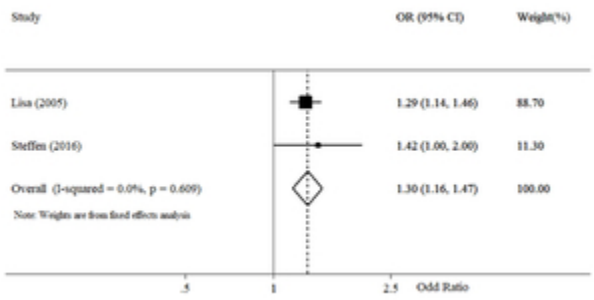

Figure 2: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with overweight [overweight versus not overweight].

26x14mm (300 x 300 DPI)

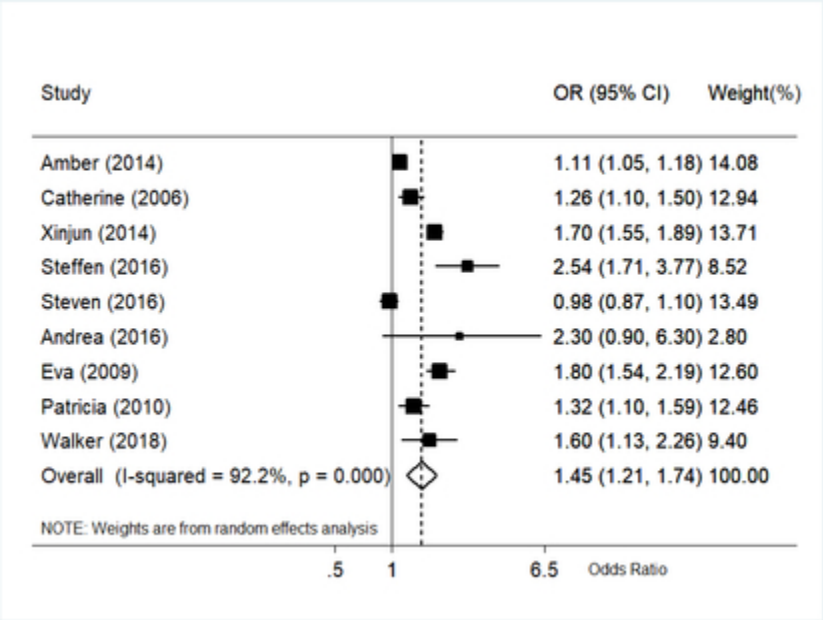

Figure 3: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with obesity [obese versus not obese].

34x26mm (300 x 300 DPI)

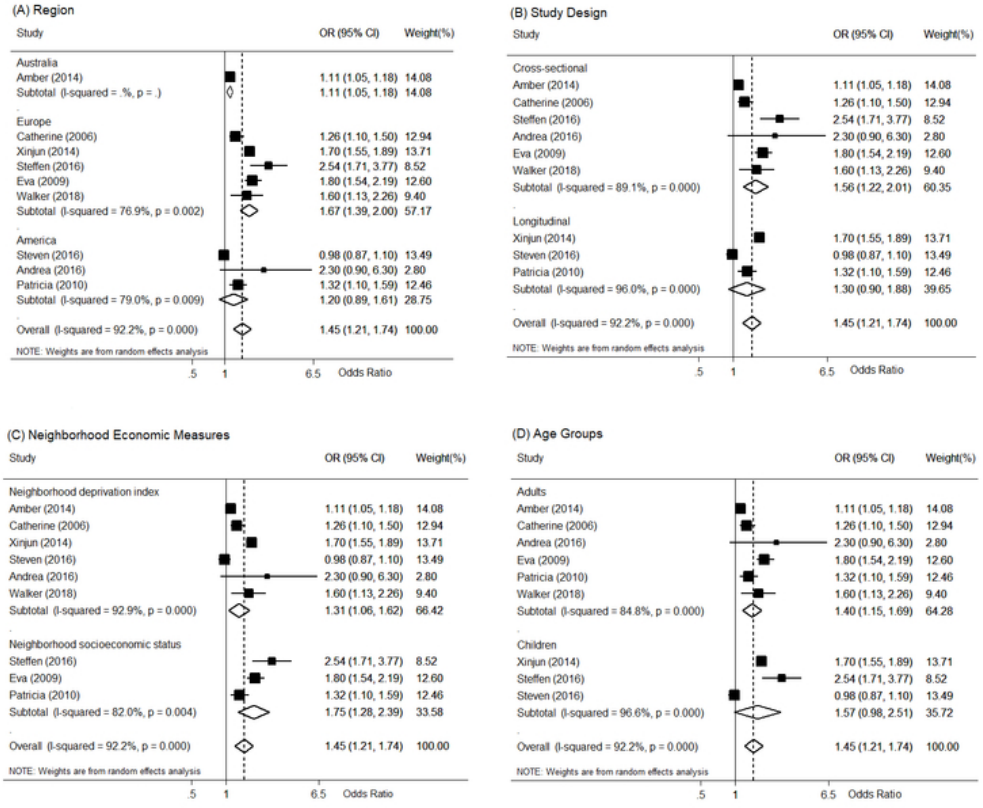

Figure 4: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with obesity [obese versus not obese], by subgroups.

62x51mm (300 x 300 DPI)

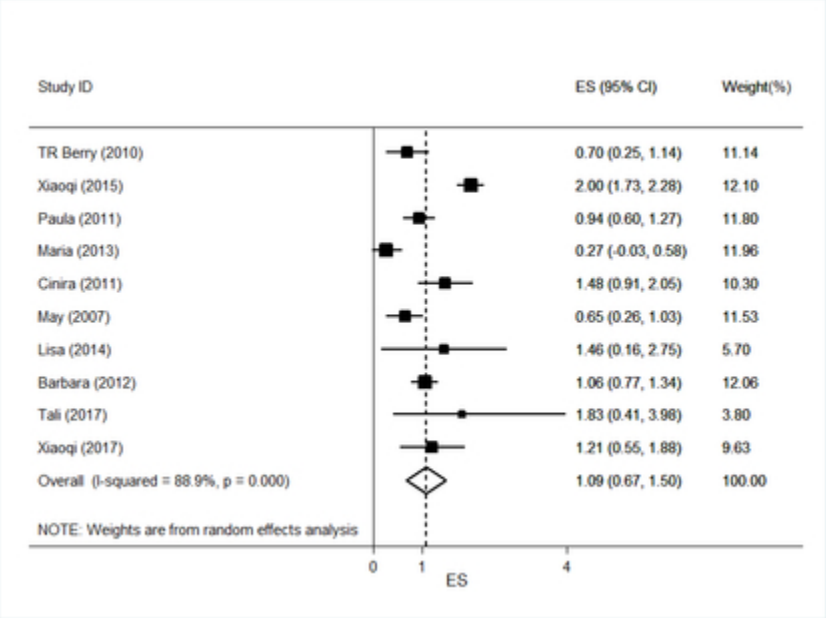

Figure 5: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index.

35x26mm (300 x 300 DPI)

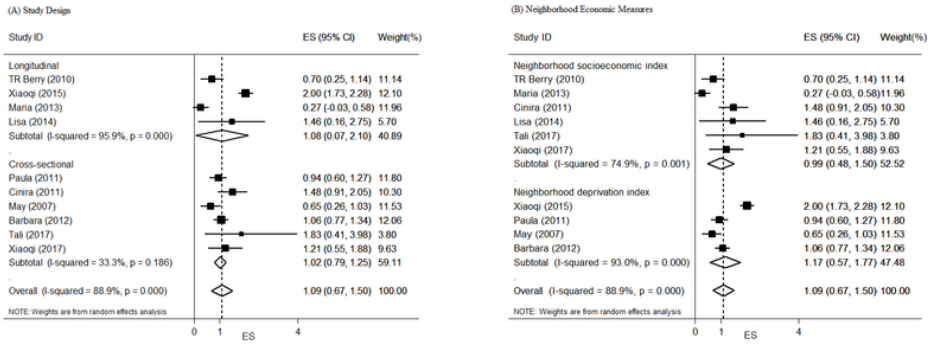

Figure 6: Forest plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index, by subgroups.

71x28mm (300 x 300 DPI)

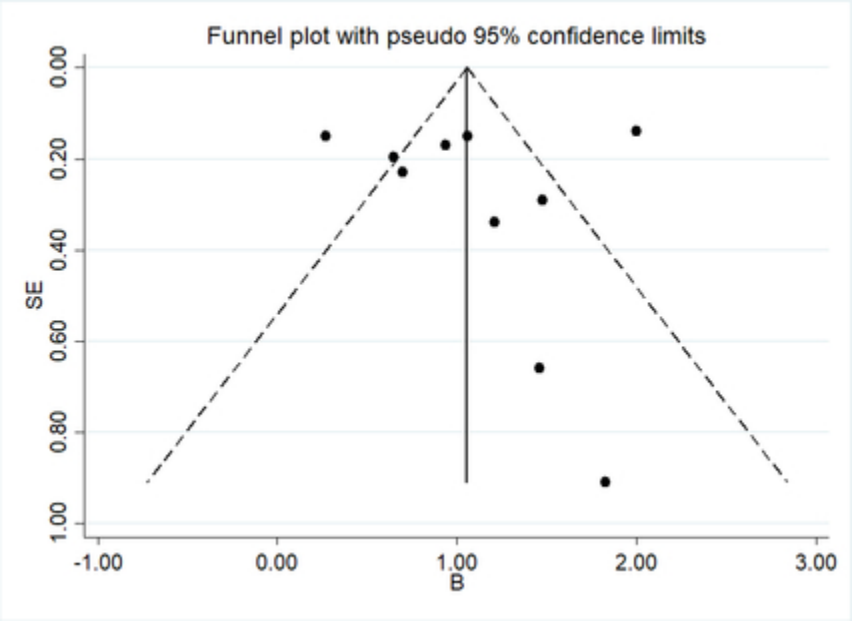

Figure 7: Funnel plot of association of neighborhood socioeconomic status (NSES) [Low NSES versus high NSES] with body mass index.

36x26mm (300 x 300 DPI)

PubMed Search strategy

Search	Query	Hits*
#1	(((((((Body Weight[MeSH Terms]) OR Body Mass Index[MeSH Terms]) OR Body weight[Title/Abstract]) OR Weight[Title/Abstract]) OR Obesity[Title/Abstract]) OR Overweight[Title/Abstract]) OR Over-weight[Title/Abstract]) OR BMI[Title/Abstract]	1049827
#2	((((((((((((Residence Characteristics/statistics and numerical data[MeSH Terms]))) OR Residence Characteristics/standards[MeSH Terms]) OR Residence Characteristics/economics[MeSH Terms]) OR Poverty Areas[MeSH Terms]) OR neighborhood socioeconomic*[Title/Abstract]) OR neighbourhood socioeconomic *[Title/Abstract]) OR neighborhood-level socioeconomic*[Title/Abstract]) OR neighbourhood-level socioeconomic*[Title/Abstract]) OR neighborhood socio-economic*[Title/Abstract]) OR neighbourhood socio-economic *[Title/Abstract]) OR neighborhood-level socio-economic*[Title/Abstract]) OR neighbourhood-level socio-economic*[Title/Abstract] OR index of multiple deprivation*[Title/Abstract]	15170
#3	#1 AND #2	4,005

*= *Date of search: September 25, 2019*

PRISMA Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4-5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	4-5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5-6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	5-6
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	5-6
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	6-7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	6

PRISMA Checklist

Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (I^2) for each meta-analysis.	6

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	6-7
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	6-7
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7-8
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7-8
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	8
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	7-8
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	7-8
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	8-9
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	8-9
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	9-11
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	11
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	11
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	12

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097.

PRISMA Checklist

doi:10.1371/journal.pmed1000097

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