Income and obesity: what is the direction of the relationship? A systematic review and meta-analysis

Tae Jun Kim, Olaf von dem Knesebeck

ABSTRACT

Objective It was repeatedly shown that lower income is associated with higher risks for subsequent obesity. However, the perspective of a potential reverse causality is often neglected, in which obesity is considered a cause for lower income, when obese people drift into lower-income jobs due to labour–market discrimination and public stigmatisation. This review was performed to explore the direction of the relation between income and obesity by specifically assessing the importance of social causation and reverse causality.

Methods A systematic literature search was conducted in January 2017. The databases Medline, PsycINFO, Sociological Abstracts, International Bibliography of Social Sciences and Sociological Index were screened to identify prospective cohort studies with quantitative data on the relation between income and obesity. Meta-analytic methods were applied using random-effect models, and the quality of studies assessed with the Newcastle-Ottawa Scale.

Results In total, 21 studies were eligible for meta-analysis. All included studies originated from either the USA (n=16), the UK (n=3) or Canada (n=2). From these, 14 studies on causation and 7 studies on reverse causality were found. Meta-analyses revealed that lower income is associated with subsequent obesity (OR 1.27, 95% CI 1.08 to 1.47; risk ratio 1.52, 95% CI 1.08 to 2.13), though the statistical significance vanished once adjusted for publication bias. Studies on reverse causality indicated a more consistent relation between obesity and subsequent income, even after taking publication bias into account (standardised mean difference −0.15, 95% CI −0.30 to 0.01). Sensitivity analyses implied that the association is influenced by obesity measurement, gender, length of observation and study quality.

Conclusions Findings suggest that there is more consistent evidence for reverse causality. Therefore, there is a need to examine reverse causality processes in more detail to understand the relation between income and obesity.

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INTRODUCTION

Obesity is a major public health issue. According to a recent trend analysis in 200 countries, age-standardised prevalence of obesity increased from 3.2% to 10.8% between 1975 and 2014 in men, and from 6.4% to 14.9% in women. In this study, like in many others, obesity was defined by a body mass index (BMI) of 30 or higher. Obesity is a major risk factor for all-cause mortality, a number of non-communicable diseases and reduced quality of life.

Within social epidemiological research, income (as an indicator of the socioeconomic status; SES) was found to be inversely associated with obesity, though this relationship can be interpreted in two directions: (1) the causation hypothesis that explains lower income as a cause for subsequent obesity and (2) the perspective of a reversed causality, in which obesity is not the result, but rather the cause for lower income.

In order to describe why people with lower income are more vulnerable to obesity, the framework of social determinants of health indicates that material conditions confine one’s access to (healthy) food and healthcare, while also influencing health-related behaviours (ie, dietary behaviours and physical activity), and psychosocial factors that derive from relative deprivation (eg, control over life, insecurity, social isolation, stress).

In contrast, one important argument for reverse causality is stigma. Studies suggest that the obese are more likely to be perceived as lazy, unsuccessful, weak-willed...
disorders. By attempting to integrate the stigma and higher insecurity, social isolation, stress and mental social stressors which include decreased control over life, lower income is associated with higher levels of psychological resources as well as mental health problems. By following these two frameworks, there are psychological resources as well as mental health problems that lead to self-stigma, reduced self-esteem (ie, healthy nutrition, physical activity). Further, lower income is associated with higher levels of psychosocial stressors which include decreased control over life, and higher insecurity, social isolation, stress and mental disorders.

This work builds on a former review that examined the relative importance of causation and reverse causality in the association between education and overweight/obesity. Though education and income can be conceptualised under the broader term of the SES, specific dimensions of SES should not be regarded as interchangeable in their relation to obesity. First, income rather influences material benefits for health, while education foremost relates to knowledge to gain or retain health. Second, income and education have a different importance across the life course, since educational attainment takes place during childhood and adolescence, while wages, earning and income are generally associated with the occupation in adulthood. For these reasons, income and education have different implications for public health.

This systematic review aims to assess both directions in the link of income and obesity, in order to address the relative importance of social causation processes and reverse causality in explaining the relationship.

METHODS
A systematic review of peer-reviewed studies that addressed the relationship between income and obesity was performed and completed in January 2017. To enhance the reproducibility of our findings, this review was conducted on the basis of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. A corresponding checklist is available online (see supplementary file 1).

Medline and PsycINFO were chosen as the main health-related databases. Moreover, the sociological databases Sociological Abstracts, International Bibliography of Social Sciences and Sociological Index were considered.

For the search, the following equation was used: (adipos* OR obes* OR body-mass-index OR BMI OR ‘waist-hip ratio’ OR WHR OR ‘skinfold thickness’) AND (‘social status’ OR socioeconomic OR socioeconomic OR inequalit* OR income OR earning* OR wage*) AND (longitudinal OR prospective OR ‘panel stud*’ OR ‘cohort stud*’).

Inclusion and exclusion criteria
For inclusion, original studies had to be published in a peer-reviewed journal and contain quantitative data on the relation between income and obesity. Further initial restrictions (ie, language, publication years) were not considered.

Population
Studies were deemed eligible for inclusion if participants were part of the general population. Therefore, studies with a focus on specific population groups (ie, patient population) were excluded.

Intervention/exposure
On the one hand, studies were omitted if they did not explicitly focus on income and/or rather referred to global SES measures (eg, neighbourhood SES or SES index).

Control group
Regardless of the study’s focus on either causation or reverse causality, a specific control group or non-exposed group (eg, people with higher income or non-obese participants) had to be provided to test the unique influence of an exposure (lower income or obesity).

Outcome
Studies that used overweight as their main outcome were excluded since obesity was found to be more predictive of health-related outcomes. Therefore, studies were included if they focused on obesity, regardless of measurement (eg, BMI ≥30, age-specific and sex-specific percentiles, z-scores). For studies testing reverse causality, all types of outcomes associated with one’s own income were included (eg, wages, earnings, household income).

Study design
Finally, only studies with a prospective design were considered, since a clear direction of causation or reverse causality can hardly be drawn from cross-sectional investigations.

In case of disagreements on inclusion or exclusion, respective records were discussed by the two reviewers (TJK and Nina Marie Roesler). If a consensus could not be achieved, a third reviewer (OK) was involved until an agreement was found.

Data extraction
Studies were assessed and the following study information retrieved: author(s), study name, country or region,
type of hypothesis, population type, sample size, age at baseline, gender proportion, measurement of income and obesity as well as length of observation, and adjusted covariates. In case multiple ascertainment of income were reported within a single study, the most appropriate measure was chosen. For instance, in studies with a children population, household income better describes the child’s financial situation, while measures of parental, paternal and maternal income were the next best alternative measures, respectively. In studies with adults, however, personal wages were the most appropriate measure to characterise one’s disadvantage on the labour market, followed by earnings and household income, respectively. TJK extracted the data and performed the meta-analyses.

Data analyses
Since most studies testing the causation hypothesis used ORs and corresponding 95% CIs in their analyses, all statistics were converted to log odds and SEs. In case ORs, log odds or SE were not readily available, effect sizes were estimated on basis of alternative statistics such as t value or P value and sample size. In contrast to the studies on social causation, which mostly referred to a binary outcome (obese vs non-obese), studies on reverse causality rather examined a continuous variable (income), mostly based on unstandardised regression coefficients. In order to provide a better comparability in the meta-analysis, these coefficients were transformed into standardised mean differences (SMD). For the meta-analyses of both hypotheses, effect sizes from fully adjusted models were taken, if available. Random-effect models were employed, and pooled estimates weighted with the restricted maximum likelihood estimator. Cochran’s Q test and Higgin’s I2 measure were calculated to evaluate the proportional degree of heterogeneity. Finally, stratified meta-analyses were run to reveal potential moderating effects (ie, study region, population type, measurement of obesity, gender, time lag between baseline and follow-up, and study quality).

To test impeding publication bias, Egger’s regression test and the trim-and-fill-method were used. The visualisation and calculation of effect sizes, pooled estimates, sensitivity analyses and publication bias were executed with R and the packages ‘esc’ and ‘metafor’.

Study quality
In order to assess the quality of non-randomised studies in meta-analyses, we referred to the Newcastle-Ottawa Scale for cohort studies (NOS). The NOS includes a total of nine items across three dimensions (ie, sample selection, comparability of cohorts, the assessment of outcome). However, two of nine criteria could hardly be applied to studies testing the reverse causality hypothesis as they focused on an outcome that was explicitly non-health related. Therefore, the two questions: (1) if the outcome of interest was not present at start of study and (2) if the follow-up duration was long enough for the outcome to occur, were excluded to provide a better precision of the NOS checklist. The application of the NOS checklist was carried out by TJK and OK and discussed in case of divergences.

RESULTS
Literature search
The inclusion and exclusion of studies is shown in figure 1. Through the initial screening of all five databases, 3955 records were found. After removing duplicates,
3027 titles and abstracts were screened for eligibility. Hereafter, another 2941 records were excluded. The full texts of the remaining 86 records were then screened for eligibility, from which 63 were dismissed. A detailed summary of reasons of exclusion is accessible online (see online supplementary file 2). Finally, 21 articles met all predefined inclusion criteria and were considered for meta-analysis. In an additional screening of the references of included studies, no further eligible records were found. Overall, 14 studies addressed the social causation and 7 the reverse causality hypothesis (see table 1 for an overview of the included studies). Information about the quality of the studies according to the NOS checklist is available online (see online supplementary file 3).

Studies testing the causation hypothesis
In 10 of the studies investigating the causation hypothesis, ORs were documented, while in four studies risk ratios (RRs) were documented. Pooled estimates indicate the likelihood or risk for subsequent obesity among people with a low income compared with those having a high income (figure 2). Overall, results reveal a higher chance (OR 1.27, 95% CI 1.10 to 1.47) and an increased risk (RR 1.52, 95% CI 1.08 to 2.13) for obesity among low-income groups. Across studies referring to ORs, 4 of the 10 studies revealed statistically significant effects. In terms of RRs, two out of four were significant. None of the studies analysing causation indicated a positive relationship. For the 10 studies with ORs, a statistically significant publication bias was detected (see online supplementary file 4). Egger’s regression test: z=5.0846, P<0.0001). After the imputation of studies to correct for publication bias, the OR decreased considerably and became statistically insignificant (adjusted OR 1.10, 95% CI 0.90 to 1.34). And though no publication bias could be detected for the four studies testing the causation hypothesis with RRs, an imputation of studies to adjust for potential publication bias yielded a decreased and statistically insignificant effect size for this meta-analysis (adjusted RR 1.16, 95% CI 0.73 to 1.82) (see online supplementary file 5).

Studies testing reverse causality
In seven studies that analysed the reverse causality hypothesis (figure 3), the pooled estimate (SMD), which expresses the size of the effect in each study relative to the variability observed, was −0.15 (95% CI −0.30 to 0.001), implying that people with obesity had a significantly lower income, when compared with the non-obese. This effect was statistically significant in five studies, while one study found a positive effect, and one study revealed a relationship that was statistically insignificant. Through the test for funnel plot asymmetry, no publication bias was detected. The effect sizes did not change after the imputation to adjust for publication bias (see online supplementary file 6).

Sensitivity analyses
In order to reveal potential moderating effects, stratified meta-analysis were performed (table 2). Sensitivity analyses showed that the majority of included studies were conducted in the USA (causation: 71%; reverse causality: 85%), whereas the only other study countries were the UK (causation: 21%) and Canada (causation: 7%; reverse causality 14%). Furthermore, the stratification for population revealed that causation mostly relied on children populations (79%), while studies on reverse causality exclusively focused on adults. The results for both region and population, however, remained fairly inconsistent, and did not reveal a clear trend.

According to studies on the causation hypothesis, higher effect sizes were evident when the height and weight of participants was actually measured instead of using a self-report (OR 1.48, 95% CI 1.04 to 2.10; RR 1.73, 95% CI 1.46 to 2.06), when the observation period exceeded 10 years (OR 1.59, 95% CI 1.11 to 2.27), and when the study quality was assessed as high (OR 1.40, 95% CI 1.06 to 1.83; RR 1.88, 95% CI 0.95 to 3.74). Subgroup analyses for gender could not be performed for studies analysing causation since gender-specific results were not documented.

In terms of the reverse causality hypothesis, the subgroup analysis of gender showed that the relation between obesity and subsequent income was more pronounced among women (SMD −0.16, 95% CI −0.30 to 0.02) than men (SMD −0.07, 95% CI −0.16 to 0.01). Similar to the studies on causation, it was shown that a longer observation period (>10 years) was associated with an effect size increase (SMD −0.52, 95% CI −0.62 to 0.41). The same pattern was found in the rating of higher study quality (SMD −0.52, 95% CI −0.62 to 0.41).

Heterogeneity between studies
With reference to figures 2 and 3, degrees of heterogeneity were relatively high in both meta-analyses that tested the causation hypothesis (I²=89.9% and 83.1%) and studies that referred to reverse causality between income and obesity (I²=98.5%). This furthermore indicates that the observed variance between studies is more likely to occur due to heterogeneity than chance alone (figures 1 and 2). High degrees of heterogeneity were also observed within most subgroup analyses (table 2).

DISCUSSION
Main findings
The results of this review revealed statistically significant effects of income on obesity (social causation) as well as of obesity on income (reverse causality). Therefore, individuals exposed to lower income are more likely to develop obesity, and the obese have lower wages when compared with their non-obese counterparts. However, after adjustments for publication bias, only the reverse causality hypothesis remained significant, whereas the meta-analytical association between lower income and subsequent
<table>
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<tr>
<th>Author, study</th>
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<th>Population</th>
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<th>Age at baseline</th>
<th>Gender (male %)</th>
<th>Income measure</th>
<th>Obesity measure</th>
<th>Follow-up duration</th>
<th>Covariates in multivariate analysis</th>
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<tr>
<td>Brophy et al&lt;sup&gt;40&lt;/sup&gt;</td>
<td>UK (national)</td>
<td>Causation</td>
<td>Children</td>
<td>17 561</td>
<td>5 (mean)</td>
<td>NA</td>
<td>Income</td>
<td>95th BMI-percentile</td>
<td>4 years</td>
<td>Ethnic group, birth weight, enjoyment of physical activity, sedentary behaviour (watching TV), indoor activities, early introduction of solid food, smoking near child, mothers prepregnancy weight, education.</td>
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<tr>
<td>Chaffee et al&lt;sup&gt;41&lt;/sup&gt;</td>
<td>USA (national)</td>
<td>Causation</td>
<td>Women</td>
<td>4780</td>
<td>40 (mean)</td>
<td>0</td>
<td>Household income</td>
<td>BMI ≥30</td>
<td>31 years</td>
<td>Birth outside the USA, urban residence as a child, and residence in the South as a child, maternal variables (age, marital status, smoking during pregnancy, educational attainment, pregnancy BMI, previous excessive/inadequate gestational weight gain).</td>
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<td>Chia&lt;sup&gt;42&lt;/sup&gt;</td>
<td>USA (national)</td>
<td>Causation</td>
<td>Children</td>
<td>3958</td>
<td>8.6 (mean)</td>
<td>51.3</td>
<td>Family income</td>
<td>95th BMI-percentile</td>
<td>6 years</td>
<td>Mother's characteristics (education, armed forces qualification test, age at birth of child, health limitations, migration status, marital status, overweight/obesity, living with both parents at age 14), child's characteristics (age, gender, region of residence, birth weight, firstborn status, race, breast feeding), household size.</td>
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<tr>
<td>Demment et al&lt;sup&gt;43&lt;/sup&gt;</td>
<td>USA (New York state)</td>
<td>Causation</td>
<td>Children</td>
<td>595</td>
<td>2 (mean)</td>
<td>53.0</td>
<td>Family income</td>
<td>BMI z-scores</td>
<td>16 years 2 years</td>
<td>Mother's age at time of delivery, multiparty, maternal overweight/obesity, child's characteristics (birth weight, sex, ADHD medication use, asthma medication use, antidepressant medication use, puberty status, early life rapid weight gain).</td>
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<td>Author, study</td>
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<td>Population</td>
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<tr>
<td>Goisis et al 44</td>
<td>MCS</td>
<td>UK</td>
<td>Children</td>
<td>11965</td>
<td>5 (mean)</td>
<td>50.8</td>
<td>Family income</td>
<td>95th BMI-percentile</td>
<td>8 years</td>
<td>Mother smoking during pregnancy, length of breast feeding, maternal BMI, early introduction to solid foods, child’s gender, physical activity (frequency of sport, active playing with parent, use of a playground, use of a bike), sedentary behaviour (watching TV, PC use), bedtime, fruit portion per day, skipping breakfast, sweet drinks consumption.</td>
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<td>Hoyt et al 45</td>
<td>CYGNET</td>
<td>USA</td>
<td>Girls</td>
<td>174</td>
<td>8–10 (range)</td>
<td>0</td>
<td>Household income</td>
<td>95th BMI-percentile</td>
<td>4 years</td>
<td>Race/ethnicity, baseline BMI, puberty status, year of outcome measure, no of street segments household size, education (of financial provider), neighbourhood SES, food and service retail scale.</td>
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<tr>
<td>Jo 46</td>
<td>ECLS-K</td>
<td>USA</td>
<td>Children</td>
<td>9287</td>
<td>5.9 (mean)</td>
<td>0.51</td>
<td>Family income</td>
<td>95th BMI-percentile</td>
<td>9 years</td>
<td>Grade level, race, gender, household size, mother's age, father's age, school lunch, school fixed effects.</td>
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<td>Kakinami et al 47</td>
<td>QLSCD</td>
<td>Canada (Québec)</td>
<td>Children</td>
<td>698</td>
<td>9.2 (mean)</td>
<td>45.6</td>
<td>Household income</td>
<td>85th BMI-percentile</td>
<td>12 years</td>
<td>Child’s birth weight and sex, mother’s education and migration status.</td>
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<td>Kim and Leigh 48</td>
<td>PSID</td>
<td>USA</td>
<td>Adults</td>
<td>6312</td>
<td>41.9 (mean)</td>
<td>0.85</td>
<td>Log hourly wage</td>
<td>BMI ≥30</td>
<td>4 years</td>
<td>Age, sex, race, marital status, education, health insurance, smoking, region of residence, survey year.</td>
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<tr>
<td>Lee et al 49</td>
<td>Add health</td>
<td>USA</td>
<td>Adolescents</td>
<td>9730</td>
<td>12–19 (range)</td>
<td>49.2</td>
<td>Poverty status</td>
<td>BMI ≥30</td>
<td>7 years</td>
<td>Age, low parental education, family structure, trouble paying bills, neighbourhood poverty, parental monitoring (watching TV, eating dinner, low-parent-child interaction, no curfew, full-time working mother), physical activity, skipping breakfast, inadequate sleep, race/ethnicity, parent obesity status.</td>
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<tr>
<td>Lee et al.²⁰</td>
<td>USA (national)</td>
<td>Causation</td>
<td>Children, adolescents</td>
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<td>3–15 (range)</td>
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<td>Family income</td>
<td>95th BMI percentile</td>
<td>15 years</td>
<td>Age, poverty status lagged, sex, race/ethnicity, birth weight, maternal variables: age, education, figure rating scale score, marital status lagged.</td>
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<tr>
<td>Pearce et al.⁵¹</td>
<td>UK (national)</td>
<td>Causation</td>
<td>Children</td>
<td>2 620 422</td>
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<td>Household income</td>
<td>95th BMI percentile</td>
<td>4 years</td>
<td>Maternal education, area deprivation, maternal social class.</td>
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<td>Salsberry and Reagan⁵²</td>
<td>USA (national)</td>
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<td>Young women</td>
<td>3707</td>
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<td>Income</td>
<td>BMI ≥30</td>
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<td>Age, parental education, own education.</td>
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<td>Strauss and Knight⁵³</td>
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<td>Children</td>
<td>2913</td>
<td>0–8 (range)</td>
<td>56.0</td>
<td>Family income</td>
<td>95th BMI percentile</td>
<td>6 years</td>
<td>Maternal BMI, initial weight-for-height z-score, gender, race, maternal education, marital status, cognitive score, emotional score.</td>
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<td>Amis et al.⁵⁴</td>
<td>USA (national)</td>
<td>Reverse causality</td>
<td>Adolescents</td>
<td>11308</td>
<td>16 (mean)</td>
<td>47.2</td>
<td>Annual income</td>
<td>95th BMI percentile</td>
<td>13 years</td>
<td>Age, sex, race, no of siblings, mother’s education, mother works, father works, closeness to mother, closeness to father, school skipped, grade repeated, attention problem, watching TV (hours), playing sports, playing computer games, hanging out with friends, type of school, neighbourhood environment, mental health, general health, smoking, alcohol use, drug use, ever had sex.</td>
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<tr>
<td>Baum and Ford⁵⁵</td>
<td>USA (national)</td>
<td>Reverse causality</td>
<td>Young adults</td>
<td>51 500 (PY)</td>
<td>28–31 (range)</td>
<td>51.7</td>
<td>Log real wage</td>
<td>BMI ≥30</td>
<td>17 years</td>
<td>Race, age, education, marital status, no of children, human capital accumulation, area of residence, local unemployment rate, industry working in, AFQT score (Armed Forces Qualifying Test), migration status, speaking foreign language, mother’s education, father’s education, siblings, rotter test score (efficacy), attitudes about family roles, health limitations. At age 14: lived with both parents, received magazines, received newspaper, library card, area of residence, mother worked.</td>
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<tr>
<td>Cawley and Danziger [56] WES</td>
<td>USA (national)</td>
<td>Reverse causality</td>
<td>Women</td>
<td>874</td>
<td>18–54 (range)</td>
<td>0</td>
<td>Earnings</td>
<td>BMI ≥30</td>
<td>6 years</td>
<td>No of children the respondent cares for, the no of children between the ages of 0 and 2 that the respondent cares for, indicator variables for no job market skills, low job market skills, less than a high school education, more than a high school education, one of the respondent’s children has a physical or mental health problem, respondent is currently cohabitating with a husband or boyfriend, never married, age, wave 3, wave 4, respondent has a conviction for other than a traffic offence, and respondent has a learning disability.</td>
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<td>Conley et al [57] PSID</td>
<td>USA (national)</td>
<td>Reverse causality</td>
<td>Adults</td>
<td>3340</td>
<td>46–49 (range)</td>
<td>46.5</td>
<td>Log wages</td>
<td>BMI ≥30</td>
<td>18 years</td>
<td>Educational attainment, labour market experience, age of youngest child and age.</td>
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<td>Han et al [56] NLSY79</td>
<td>USA (national)</td>
<td>Reverse causality</td>
<td>Adolescents</td>
<td>1974</td>
<td>16–20 (range)</td>
<td>54.1</td>
<td>Hourly wage</td>
<td>BMI ≥30</td>
<td>12 years</td>
<td>Age, race, marital status, time from latest pregnancy to the interview, education of the parents, AFQT score, self-esteem, years of employment, participated in on-the-job training, area of residence, unemployment rate in the residential unit, no of private businesses at state level, average income by state, consumer price index, education, occupation, occupation requiring social interaction.</td>
</tr>
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<td>Larose et al [55] NPHS</td>
<td>Canada (national)</td>
<td>Reverse causality</td>
<td>Adults</td>
<td>3993</td>
<td>40.2 (mean)</td>
<td>50.71</td>
<td>Hourly wage rate</td>
<td>BMI ≥30</td>
<td>6 years</td>
<td>Age, presence of small children in the household, migration status, area of residence, marital status, non-wage/spouse income, home ownership, education, smoking behaviour, drinking behaviour.</td>
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Table 1 Continued
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<tr>
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</thead>
<tbody>
<tr>
<td>Mason NLSY97</td>
<td>USA (national)</td>
<td>Reverse causality</td>
<td>Young adults</td>
<td>2427</td>
<td>12–17</td>
<td>50.72</td>
<td>Income</td>
<td>BMI ≥30</td>
<td>9 years</td>
<td>Education, parental status, work experience, occupation, race, socioeconomic background, household income, mother’s education, father’s education, health limitations, (Armed Services Vocational Aptitude Battery).</td>
</tr>
</tbody>
</table>

Add Health, National Longitudinal Study of Adolescent to Adult Health; ADHD, Attention Deficit Hyperactivity Disorder; BMHP1, Bassett Mothers Health Project; BMI, body mass index; Cygnet Study, Cohort Study of Young Girls Nutrition, Environment and Transitions; ECLS-K, Early Childhood Longitudinal Study Kindergarten; MOS, Millennium Cohort Study; NA, not available; NCMPP, National Child Measurement Programme; NLSY (97), US National Longitudinal Survey of Youth (1997); NPHS, Canadian National Population Health Survey; PSID, Panel Study of Income Dynamics; PY, person-years; QLSCD, Québec Longitudinal Study of Child Development; SECCYD, Study of Early Child Care and Youth Development; SES, socioeconomic status; WES, Women’s Employment Study.
obesity longitudinally (thus enabling to carve out the direction of the respective influence), the question of causality cannot be fully answered due to two main reasons. On the one hand, the methodological issue remains that (cohort) studies are not able to adjust for transitions between the individual income status as well as the obesity status that take place between the baseline and the follow-up survey. Thus, the results of longitudinal observational studies

Figure 2  Pooled estimates of studies testing the causation hypothesis. RE, random effects.

Figure 3  Pooled estimates of studies testing the reverse causality hypothesis. RE, random effect; SMD, Standardised mean difference.
Table 2  Sensitivity analyses

<table>
<thead>
<tr>
<th></th>
<th>Social causation hypothesis</th>
<th>Reverse causality hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>OR (CI), I²</td>
</tr>
<tr>
<td>Overall</td>
<td>10</td>
<td>1.27 (1.10 to 1.47), 90%</td>
</tr>
<tr>
<td>Study region</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>8</td>
<td>1.22 (1.06 to 1.40), 88%</td>
</tr>
<tr>
<td>UK</td>
<td>1</td>
<td>1.19 (0.97 to 1.45), NA</td>
</tr>
<tr>
<td>Canada</td>
<td>1</td>
<td>3.04 (1.69 to 5.47), NA</td>
</tr>
<tr>
<td>Population</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>8</td>
<td>1.33 (1.08 to 1.64), 93%</td>
</tr>
<tr>
<td>Adolescents</td>
<td>1</td>
<td>1.25 (0.98 to 1.59), NA</td>
</tr>
<tr>
<td>Adults</td>
<td>1</td>
<td>1.15 (1.06 to 1.25), NA</td>
</tr>
<tr>
<td>Obesity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-report</td>
<td>5</td>
<td>1.20 (1.03 to 1.41), 88%</td>
</tr>
<tr>
<td>Measured</td>
<td>5</td>
<td>1.48 (1.04 to 2.10), 84%</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Female</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Observation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;5 years</td>
<td>3</td>
<td>1.15 (1.07 to 1.25), 0%</td>
</tr>
<tr>
<td>5–10 years</td>
<td>2</td>
<td>1.11 (0.98 to 1.25), 30%</td>
</tr>
<tr>
<td>&gt;10 years</td>
<td>5</td>
<td>1.59 (1.11 to 2.27), 88%</td>
</tr>
<tr>
<td>Study quality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>3</td>
<td>1.09 (1.00 to 1.18), 57%</td>
</tr>
<tr>
<td>Medium</td>
<td>5</td>
<td>1.47 (1.04 to 2.08), 90%</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
<td>1.40 (1.06 to 1.83), 40%</td>
</tr>
</tbody>
</table>

n, number of studies; NA, not available; RR, risk ratios; SMD, standardised mean difference.

should be regarded as a mere tendency, and must be interpreted with caution. On the other hand, there is reason to believe that processes of social causation are not simply replaced by reverse causality during the life course, but rather coexist in one’s biography. As noted above, it can be assumed that causation processes and reverse causality rather augment than neutralise each other, so that the link between income and obesity is likely to follow a bidirectional relationship. Fourth, a further limitation of studies testing the causation hypothesis is the heterogeneity of the low-income control groups. In this regard, the reference groups varied substantially, which limits the comparability between different income measures. In terms of studies testing the reverse causality, comparability was not as problematic as all studies referred to a non-obese reference that was defined by a BMI lower than 30. Fifth, and even though the subgroup analyses revealed a few factors that may moderate the relationship between income and obesity, results for the reverse causality hypothesis were mostly based on the same subgroups. Finally, the capacity of Egger’s regression test to detect publication bias depends on the number of included studies. Therefore, there is a clear lack of statistical power in Egger’s regression test of studies that used RRs (n=4), which has to be viewed as a further limitation of this study. In addition, the trim-and-fill method of these studies led to a substantially decreased and statistically insignificant effect size (adjusted RR 1.10, 95% CI 0.90 to 1.34), further implying the inconsistencies of results testing the causation hypothesis.

Future research
By taking these limitations into account, future studies should aim at investigating the relation between income and obesity outside of western societies. An extended view on the association in other countries could aid in detecting cultural influences that frame the magnitude of both causation processes and reverse causality between income and obesity. Moreover, and in order to clarify potential bidirectional effects between income and obesity, future research should investigate the interaction between causation processes and reverse causality in a single cohort over the life course. Finally, future studies could focus on detecting other factors that may influence the relation between income and obesity for both hypotheses.
CONCLUSIONS

This review was performed to give an overview of causation processes in the link between income and obesity, while also investigating a reverse causality between these two variables. Meta-analyses revealed significant links between lower income and the risk of obesity as well as obesity and subsequent income (reverse causality hypothesis). However, after adjusting for publication bias, the relation between lower income and the risk of subsequent obesity vanished, indicating a higher likelihood of unpublished studies due to negative findings. In contrast, results from studies testing the reverse causality perspective remained consistent even after adjusting for potential publication bias. Therefore, a stronger consideration of potential reverse causality is needed to address income-related inequalities in obesity.

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Data sharing statement We retrieved all data for the meta-analyses from already published material. Therefore, the data are available in the respective articles.

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