Body mass index and the risk of disability retirement: A systematic review and meta-analysis

Rahman Shiri,[1] Kobra Falah-Hassani,[2] Tea Lallukka[1,3]

[1] Finnish Institute of Occupational Health, Helsinki, Finland

[2] University of Oulu and Oulu University Hospital, Oulu, Finland

[3] Department of Public Health, University of Helsinki, Helsinki, Finland

Running title: Body mass index and disability retirement

Abstract word count: 250

Text word count: 3,341

Number of tables: 1

Number of figures: 4

Number of web tables: 3

Number of web figures: 13

Correspondence to:

Rahman Shiri

Finnish Institute of Occupational Health

P.O. Box 18

FI-00032 Työterveyslaitos, Helsinki

Email: rahman.shiri@ttl.fi

Ethics approval

Not applicable

Funding source

TL is supported by the Academy of Finland (Grants #287488 and #319200), and by the Finnish Work Environment Fund (Grant #117308). RH is supported by the Academy of Finland (Grant #319200).

Conflict of interest

The authors declare that they have no conflicts of interest.

Contributors' Statement

RS planned the study; conducted literature searches; screened the studies; extracted data; assessed the studies for the risk of bias; carried out the meta-analyses and wrote the manuscript. KFH screened the studies; extracted data; assessed the studies for the risk of bias and critically revised the manuscript. TL planned the study and critically revised the manuscript.

What is already known about this subject?

- Physical workload factors and obesity increase the risk of all-cause disability retirement.
- Obesity may strengthen the adverse effects of physical workload factors on disability retirement.

What are the new findings?

- There is a J-shaped relation between body mass index and disability retirement in both men and women. Both underweight and overweight increase the risk of disability retirement.
- Obesity markedly increases the risk of disability retirement due to musculoskeletal disorders, cardiovascular diseases and mental disorders.

How might this impact on policy or clinical practice in the foreseeable future?

- Prevention of unhealthy weight gain can prevent not only excess body mass related illnesses but also disability retirement.
- Improvement in working conditions may partly reduce excess body mass related disability retirement.

ABSTRACT

Objective: To determine the associations of body mass index (BMI) with all-cause and cause-specific disability retirement.

Methods: Literature searches were conducted in PubMed, Embase and Web of Science from their inception through May 2019. Twenty-seven (25 prospective cohort and two nested case-control) studies consisting of 2,199,632 individuals qualified for a meta-analysis. Two reviewers independently assessed the methodological quality of the included studies. We used a random-effects meta-analysis, assessed heterogeneity and publication bias, and performed sensitivity analyses.

Results: There were a large number of participants and the majority of studies were rated at low/moderate risk of bias. There was a J-shaped relationship between BMI and disability retirement. Underweight (hazard ratio/risk ratio (HR/RR)=1.20, 95% CI 1.02-1.41), overweight (HR/RR=1.13, CI 1.07-1.19), and obese individuals (HR/RR=1.52, CI 1.36-1.71) were more commonly granted all-cause disability retirement than normal weight individuals. Moreover, overweight increased the risk of disability retirement due to musculoskeletal disorders (HR/RR=1.26, CI 1.15-1.39) and cardiovascular diseases (HR=1.73, CI 1.24-2.41), and obesity increased the risk of disability retirement due to musculoskeletal disorders (HR/RR=1.66, 1.42-1.94), mental disorders (HR=1.29, 1.04-1.61) and cardiovascular diseases (HR=2.80, 1.85-4.24). The association between excess body mass and all-cause disability retirement did not differ between men and women and was independent of selection bias, performance bias, confounding, and adjustment for publication bias.

Conclusions: Obesity markedly increases the risk of disability retirement due to musculoskeletal disorders, cardiovascular diseases and mental disorders. Since the prevalence of obesity is increasing globally, disease burden associated with excess body mass and disability retirement consequently are projected to increase.

Keywords: Overweight, obesity, pension, retirement

Introduction

Nearly 1% of the European general working population ages 30 years or older are granted disability retirement every year.[1 2] The rate of disability retirement increases with age,[1 3] and musculoskeletal and mental disorders are the most common causes.[4 5] Approximately a third of disability retirements in the Nordic countries are due to musculoskeletal disorders,[4-7] and 10% to 25% are due to mental disorders,[4-7] highlighting their public health and societal significance.

Obesity[8-11] and smoking[10] may increase the risk of disability retirement, while leisure-time physical activity may reduce the risk of disability retirement,[4 11] particularly disability retirement due to musculoskeletal disorders.[4] Excess body mass increases the risk of cardiovascular diseases, musculoskeletal disorders and mental disorders,[12-16] and these illnesses subsequently increase the rate of disability retirement. In addition to excess body mass, underweight appears to increase the risk of disability retirement.[9 17-19] To date, a systematic review[20] and a meta-analysis[11] on the association between body mass index (BMI) and disability retirement have previously been published. The systematic review of eight longitudinal studies[20] found a J-shaped relationship between BMI and disability retirement. Furthermore, a meta-analysis of 18 longitudinal studies[11] showed that overweight increases the risk of disability retirement by 16% and obesity by 53%. However, some of the studies included in that meta-analysis did not use normal BMI (18.5-24.9 kg/m^2)[21] as a comparison group. Moreover, that meta-analysis did not estimate the effect of underweight on disability retirement and that of BMI on cause-specific disability retirement.

Obesity may strengthen the adverse effects of physical workload factors on disability retirement. Physical workload factors increase the risk of disability retirement.[22-24] Lifting of heavy loads,[22 24] and working in bent forward or twisted position[22] increase the risk of all-cause disability retirement (any cause), particularly disability retirement due to musculoskeletal disorders.[22] A prospective cohort study found higher risk of all-cause disability retirement and disability retirement due to musculoskeletal disorders in participants with overweight or obesity who were exposed to high level of workload factors than in participants with overweight or obesity who were exposed to low or intermediate level of physical workload factors.[22] It is important to identify individuals at increased risk of disability retirement to be able to target workplace and healthcare interventions.

The aim of the current systematic review and meta-analysis of prospective cohort studies was to determine the associations of BMI with all-cause and cause-specific disability retirement.

Methods

Search strategy

We used the PRISMA statement[25] to develop the review protocol and meta-analysis. The review protocol was registered in PROSPERO (CRD42018103110). The first author searched PubMed, Embase and Web of Sciences databases from their inception through May 2019, using combinations of MeSH terms (PubMed), Emtree terms (Embase) and text words (Supplementary Table 1). The first author conducted additional search in Google Scholar. There were no restrictions on age or sex of participants, or language of publications. The reference lists of included articles and previous reviews[11 20] on this topic were also hand-searched for additional reports that might be relevant.

Inclusion and exclusion criteria

Two reviewers (RS and KFH) independently screened the titles, abstracts and full texts of relevant reports to identify studies on the association between BMI and disability retirement. Only prospective cohort studies and nested case control studies were eligible for inclusion in the review. We excluded studies on patient populations, birth weight, studies that combined disability retirement with sickness absence in a single analysis, and studies on intention to retire early. To avoid duplication bias, we included only one report from multiple publications of a single study for each outcome of interest. Of multiple publications, we included the publication reporting maximally adjusted risk estimates and/or including total study sample in the analysis (Supplementary material). Disagreements between the reviewers were resolved through discussion.

Quality assessment

Two reviewers (RS and KFH) independently assessed the methodological quality of the included studies using criteria adapted from the Effective Public Health Practice Project tool.[26] We assessed five sources of bias: selection bias, performance bias, detection bias, attrition bias, and confounding (Supplementary Table 2). Disagreements between the raters were resolved through discussion.

Meta-analysis

We extracted the details of the studies included in the meta-analysis such as year of publication, country, follow-up time, study population, age range, sex, sample size, measurement method for height and weight, BMI cut-off points, and method of assessing disability retirement. For each study, the first author abstracted maximally adjusted risk estimates for underweight, overweight and obesity, together with their 95% confidence intervals. The extracted data were checked by the second author. We extracted data for four outcomes; disability retirement due to any cause (all-cause), musculoskeletal disorders, cardiovascular diseases, and mental disorders. For the four prospective cohort studies[1 3 27 28] that reported odds ratios (ORs), we converted ORs to risk ratios (RRs),[29] because in two[1 27] of the four studies, the cumulative incidence was more than 5%. The estimated RRs were, however, almost identical to the ORs.

We defined underweight as BMI >18.5 kg/m^2, normal weight as BMI between 18.5 and 24.9 kg/m^2, overweight as BMI between 25.0 and 29.9 kg/m^2, overweight/obesity as BMI >25 kg/m^2 and obesity as BMI >30 kg/m^2.[21] In one study,[28] we defined overweight/obesity as BMI >24 kg/m^2. We defined disability retirement as temporary (for a fixed period of time) or permanent (unable to return to work again) work disability.

For studies[30-34] that reported an estimate for 1-SD[30 32] or 1-unit[31 33 34] increase in BMI, we calculated the effect sizes for overweight and obesity. First, we transformed the effect size and its confidence interval into natural logarithm, calculated an estimate for 1-unit from 1-SD, and then multiplied a value for 1-unit by 5 to get an estimate for overweight and by 10 to get an estimate for obesity. This assumes that on average employees with overweight have a BMI five units higher (e.g. an average BMI 27 or 28) than normal weight employees (e.g., an average BMI 22 or 23), and that for employees with obesity (e.g., an average BMI 32 or 33), BMI is on average 10 units higher.

For studies[27 35] that used underweight as a reference group, a hazard ratio (HR) or RR for overweight or obesity was calculated by dividing the HR for overweight or obesity by the HR for normal weight. The standard error of the estimate for overweight or obesity was then used to calculate 95% confidence interval for the new estimate.

We performed a fixed-effect meta-analysis to combine the independent subgroups of a single study and a random-effects meta-analysis to combine the estimates of different studies.[36] The presence of heterogeneity across the studies was assessed by the I^2 statistics.[37] Subgroup analyses were performed with regard to sex, exposure assessment method (self-reported measures vs. objective measures), adjustment for confounding factors, and other methodological quality of included studies. Meta-regression[38] was used to explore whether study-level covariates accounted for the observed heterogeneity and to test for differences in the HR between two or more subgroups. A funnel plot was used for exploring publication bias, and Egger's regression test for examining funnel plot asymmetry. Furthermore, the trim

and fill method was used to adjust for missing studies due to publication bias.[39 40] Stata, version 15 (StataCorp LP, College Station, Texas) was used for the meta-analyses.

Results

The searches identified 1228 relevant publications in PubMed, 2125 in Embase, and 1169 in Web of Sciences (Figure 1). Preliminary screening reduced the number of relevant publications to 185 reports. Ten multiple publications and 139 ineligible reports were excluded. Of 38 studies on the association between body mass index and disability retirement, we excluded 11 studies (Supplementary material). Finally, 27 studies (29 reports, N=2,199,632 participants) including 25 prospective cohort studies (27 reports)[1 3 7-9 17-19 22 27 28 30 32-35 41-51] and two nested case control studies[52 53] qualified for meta-analyses (Supplementary Table 3). There were 10 studies from Finland, six from Sweden, four from Norway, three from Denmark, two from the United State and one from Germany. One study was conducted in 11 European countries. Of 25 prospective cohort studies, 16 reported HR, five reported RR, three OR and one study reported HR and OR (two reports).

In the quality assessment of the included studies, 12 studies were rated to be at low risk of selection bias, 11 studies at moderate risk and four studies at high risk of selection bias. All studies were rated at low risk of attrition and detection biases, except two studies for attrition bias and three for detection bias. Fourteen studies measured height and weight and 13 studies used self-reported height and weight. Only two studies did not control for any confounding factors. Fourteen studies controlled their risk estimates for most confounding factors and 11 studies controlled for some confounders.

All-cause disability retirement

One study[49] reported only crude estimate for the association between BMI and all-cause disability retirement and one study[43] used normal weight without mobility disability as a reference group and reported adjusted estimates for overweight or obesity without mobility disability and adjusted estimates for overweight or obesity with mobility disability. For this study we calculated unadjusted estimates for overweight and obesity using normal weight as a reference group. The pooled unadjusted RR of these two studies was 1.44 (CI 1.32-1.57, I^2=0%, N=51,369 participants) for overweight and 2.44 (CI 2.18-2.74, I^2=0%, N=51,369 participants) for obesity.

Four prospective cohort studies[1 3 7 51] compared employees with obesity (BMI ≥30) with employees without obesity (BMI <30) for the risk of all-cause disability retirement. The pooled HR was 1.78 (CI 1.39-2.27, I^2=53%, 2 studies, N=11,853 participants) for men and the pooled HR/RR was 1.55 (CI 1.27-1.89, I^2=63%, 4 studies, N=23,834 participants) for both sexes combined. Only a single study reported an estimate for women.

Both sexes. Nineteen studies reported adjusted risk estimates; 13 studies recruited both sexes, six recruited only men and one recruited only women. A meta-analysis of the 19 studies showed a J-shaped relationship between BMI and all-cause disability retirement (Figure 2). Underweight increased the rate or risk of all-cause disability retirement by 20% (HR/RR=1.20, 95% CI 1.02-1.41, I^2=90%, 7 studies, N=1,651,668 participants), overweight by 13% (HR/RR=1.13, 95% CI 1.07-1.19, 17 studies, N=2,098,013 participants), overweight or obesity by 25% (HR/RR=1.25, 95% CI 1.17-1.32, 19 studies, N=2,124,522 participants), and obesity by 52% (HR/RR=1.52, 95% CI 1.36-1.71, 17 studies, N=2,098,013 participants) (Figure 2 and Table 1). There was no evidence of publication bias. Supplementary Figures 1-3 show the funnel plots of studies on overweight, overweight/obesity, and obesity. P value for Egger test was 0.76 for underweight, 0.43 for overweight, 0.87 for overweight/obesity and

0.93 for obesity. The trim and fill method imputed no missing studies due to publication bias for overweight, overweight/obesity, and obesity (Table 1). However, it imputed two missing studies for underweight and the pooled HR reduced to 1.09 (CI 0.93-1.27) after adjustment for publication bias. Sensitivity analyses showed that higher quality studies reported stronger positive associations between BMI and all-cause disability retirement than lower quality studies (Table 1).

Table 1: A sensitivity analysis of 19 studies that reported adjusted estimates for body mass index according to methodological quality of included studies and adjustment for publication bias

Characteristic	Overweight (BMI 25.0-29.9 kg/m^2)					Overweight or obesity (BMI ≥25 kg/m^2)					Obesity (BMI ≥30 kg/m^2)				
	Sample	HR	95% CI	I^2 (%)	*P*	Sample	HR	95% CI	I^2 (%)	*P*	Sample	HR	95% CI	I^2 (%)	*P*
Overall	2,098,013	1.13	1.07-1.19	93		2,124,522	1.25	1.17-1.32	96		2,098,013	1.52	1.36-1.71	96	
Adjustment for publication bias		1.13	1.07-1.19				1.25	1.17-1.32				1.52	1.36-1.71		
Selection bias															
Low	2,045,872	1.18	1.11-1.25	95	0.038	2,033,607	1.26	1.17-1.35	97	0.69	2,045,872	1.55	1.52-1.58	97	0.57
Moderate/high	52141	1.00	0.85-1.18	71		90915	1.22	1.03-1.44	91		52141	1.35	1.24-1.48	88	
Confounding															
Low	1,551,254	1.18	1.06-1.31	87	0.25	1,590,028	1.32	1.22-1.43	87	0.17	1,551,254	1.64	1.41-1.91	86	0.34
Moderate	546,759	1.09	1.03-1.16	91		534,494	1.18	1.10-1.27	95		546,759	1.45	1.26-1.67	96	
Performance bias															
Low	2,031,356	1.14	1.06-1.21	96	0.65	2,019,091	1.25	1.15-1.36	98	0.83	2,031,356	1.58	1.37-1.83	97	0.41
Moderate	66,657	1.09	0.96-1.24	75		105,431	1.24	1.13-1.36	76		66,657	1.43	1.23-1.68	59	
Low confounding and low selection, performance, detection and attrition biases	1,510,592	1.19	0.99-1.43	94		1,510,592	1.32	1.11-1.58	96		1,510,592	1.71	1.36-2.16	93	
Follow-up time (17 cohort studies)															
≤10 years	41,201	1.10	1.01-1.19	0	0.49	79,975	1.26	1.16-1.36	47	0.91	41,201	1.39	1.23-1.57	0	0.39
>10 years	1,919,256	1.15	1.07-1.24	93		1,919,256	1.27	1.17-1.37	96		1,919,256	1.63	1.44-1.84	93	

Meta-regression was used to test for the differences between subgroups

The association between BMI and all-cause disability retirement did not statistically significantly differ between seven prospective cohort studies with follow-up time up to 10 years and 10 cohort studies with follow-up time longer than 10 years (Table 1, Supplementary Figures 4-5).

A meta-analysis of 13 studies that recruited both sexes showed similar results (Supplementary Figure 6). Overweight increased the rate or risk of all-cause disability retirement by 14%, overweight or obesity by 24% and obesity by 43%. However, a meta-analysis of four studies consisting of 241,084 participants did not show an association between underweight and all-cause disability retirement.

Sex-specific. A sex-specific meta-analysis also showed a J-shaped relationship between BMI and all-cause disability retirement in both men and women (Supplementary Figures 7-8). In men (Supplementary Figure 7), underweight increased the risk of all-cause disability retirement by 42% (HR=1.42, 95% CI 1.12-1.79, I^2=84%, 4 studies, N= 1,503,486 participants), overweight by 10% (HR/RR=1.10, 95% CI 1.01-1.20, I^2=94%, 10 studies, N= 1,884,122 participants) and obesity by 57% (HR/RR=1.57, 95% CI 1.36-1.81, I^2=93%, 10 studies, N= 1,884,122 participants). There was no evidence of publication bias for overweight (P for Egger's test = 0.22) and obesity (P for Egger's test = 0.39) (Supplementary Figures 9-10). For underweight, Egger's test was significant (P = 0.075) and the trim and fill method imputed two missing studies. After adjustment for publication bias, the pooled HR for underweight reduced to 1.21 (CI 0.95-1.53). A sensitivity analysis showed the stronger associations of overweight and obesity with disability retirement in a meta-analysis of the studies with low risk of confounding or selection bias than a meta-analysis of the studies with

moderate risk of confounding or selection bias. On the other hand, the lower quality studies overestimated the association between underweight and disability retirement in men.

In women (Supplementary Figure 8), underweight increased the risk of all-cause disability retirement by 46% (HR=1.46, 95% CI 1.05-2.03, I^2=0%, 2 studies, N=9215 participants), overweight by 20% (HR/RR=1.20, 95% CI 1.09-1.33, I^2=37%, 6 studies, N=45,053 participants) and obesity by 59% (HR/RR=1.59, 95% CI 1.45-1.74, I^2=0%, 6 studies, N=45,053 participants). There was no evidence of publication bias for overweight and obesity. P-value for Egger's test was 0.18 for overweight and 0.26 for obesity (Supplementary Figures 11-12). Furthermore, the trim and fill method did not impute any missing studies due to publication bias. A meta-analysis of the studies with low selection and performance biases showed the stronger association of overweight with disability retirement than a meta-analysis of the studies with moderate selection or performance bias (pooled HR/RR = 1.31, CI 1.17-1.46, I^2 = 34%, 2 studies, N= 20,380 participants vs. 1.08, CI 0.95-1.22, I^2 = 0%, 4 studies, N = 24,673, P-value for the difference = 0.072).

Disability retirement due to musculoskeletal disorders

One study[43] reported unadjusted estimates for the association between BMI and disability retirement due to musculoskeletal disorders. Estimated incidence rate ratio was 1.54 (CI 1.33-1.78) for overweight and 2.58 (CI 2.14-3.11) for obesity.

Seven studies reported adjusted estimates for the association of BMI with disability retirement due to musculoskeletal disorders (Figure 3). The pooled HR was 1.25 (95% CI 0.77-2.03, 3 studies, N=1,201,182 participants) for underweight and the pooled HR/RR was 1.26 (95% CI 1.15-1.39, 6 studies, N=1,570,390 participants) for overweight, 1.34 (CI 1.22-1.47, 7 studies, N=1,605,144 participants) for overweight or obesity (BMI $\geq$25 kg/m^2) and 1.66 (CI 1.42-1.94,

6 studies, N=1,570,390 participants) for obesity. There was no evidence of publication bias. P-value for Egger's test was non-significant for underweight (P=0.23), overweight (P=0.88), overweight or obesity (P=0.86), and for obesity (P=0.67). The trim and fill method, however, imputed two missing studies for underweight and the pooled HR reduced to 1.02 (CI 0.67-1.55) after adjustment for publication bias. In a sensitivity analysis, higher quality studies reported stronger positive associations between BMI and disability retirement due to musculoskeletal disorders than lower quality studies. The pooled HR of three studies[19 34 42] consisting of 1,218,683 participants with low confounding and low selection, detection and attrition biases was 1.30 (CI 1.08-1.57) for overweight, 1.34 (CI 1.07-1.67) for overweight or obesity and 1.55 (CI 1.07-2.26) for obesity.

Disability retirement due to mental disorders

Five studies[19 22 43 46 47] provided results on the relationship between BMI and disability retirement due to mental disorders. One study[43] reported only unadjusted estimates. The estimated incidence rate ratio for this study was 1.14 (0.97-1.33) for overweight and 1.76 (CI 1.42-2.18) for obesity.[43] In a meta-analysis of four studies that provided adjusted risk estimates, underweight, overweight and overweight/obesity (BMI $\geq$25 kg/m^2) did not statistically significantly increase the risk of disability retirement due to mental disorders (Figure 4), whereas obesity increased the rate by 29% (HR=1.29, CI 1.04-1.61, I^2=83%, N=1,554,925 participants).

Disability retirement due to cardiovascular diseases

Two studies[19 22] reported adjusted HRs for the association of BMI with disability retirement due to cardiovascular diseases. The combined HR was 1.73 (CI 1.24-2.41, I^2=96%, N=1,519,770 participants) for overweight, 1.95 (CI 1.39-2.74, I^2=97%, N=1,519,770

participants) for overweight or obesity and 2.80 (95% CI 1.85-4.24, I^2=92%, N=1,519,770 participants) for obesity (Supplementary Figure 13).

Discussion

The current meta-analysis showed that there is a J-shaped relation between BMI and disability retirement. Being underweight or overweight increases the risk of disability retirement. The risk is highest for obesity, particularly the risk of disability retirement due to musculoskeletal disorders and cardiovascular diseases. Excess risk due to overweight is small for all-cause disability and none for disability retirement due to mental disorders, while it is sizable for disability retirement due to musculoskeletal disorders and cardiovascular diseases. Furthermore, the association between BMI and all-cause disability retirement is similar in both men and women.

The findings of the current meta-analysis on all-cause disability retirement are in line with the earlier meta-analysis of 18 studies.[11] However, that meta-analysis combined studies on all-cause disability retirement with studies on disability retirement due to musculoskeletal disorders in a single analysis. It did not use the WHO suggested cut-off points for normal weight, overweight and obesity. BMI values $\geq$27.0 kg/m^2 and 26.4-28.6 kg/m^2 were defined as overweight, which lead to overestimation of the association between overweight and disability retirement. Moreover, some of the studies included in that meta-analysis did not use normal BMI as a comparison group. For instance, three studies[1 3 7] used BMI <30 kg/m^2 as a comparison group, leading to underestimation of the association between obesity and disability retirement. Lastly, that meta-analysis did not report any estimate for cause-specific disability retirement.

In the present meta-analysis, we used WHO cut-off values for underweight, overweight and obesity and compared them with normal BMI for the risk of all-cause and cause-specific

disability retirement. However, a few studies used BMI <25 kg/m^2 as a comparison group, without differentiating between underweight and normal weight. This misclassification may have underestimated the strength of the associations of overweight and obesity with disability retirement. We performed subgroup meta-analyses according to study quality. The observed association between excess body mass and disability retirement was not due to selection bias, performance bias, confounding, or publication bias. The meta-analyses of the studies controlled their risk estimates for most confounding factors revealed even larger adverse effects of overweight and obesity on disability retirement than studies controlled their estimates only for some confounding factors. Moreover, the associations of overweight and obesity with disability retirement did not differ between studies measured weight and height and studies used self-reported measures. All included studies, except three collected data on disability retirement through reliable registry. There was no evidence of publication bias for overweight and obesity and adjustment for possibility of publication bias did not change the results. However, the observed association between underweight and disability retirement can be due to selection bias, confounding, or publication bias. Limiting the meta-analyses to higher quality studies or adjusting for publication bias attenuated the association between underweight and disability retirement. However, only a limited number of studies determined the effect of underweight on disability retirement.

Disability retirement imposes a considerable economic burden on society, and is usually preceded by a long sickness absence.[54] Overweight and obesity increase the risk of absent from work because of sickness.[55 56] They increase the risk of cardiovascular diseases[12] and musculoskeletal disorders,[13-15] and obesity increases the risk of mental disorders.[16] Self-reported anthropometric measurements overestimate height and underestimate weight compared with measured height and weight, particularly in individuals with overweight or

obesity,[57 58] but nonetheless self-reported height and weight are valid measures for investigating the relationship of overweight and obesity with work disability[56] and disease.[58] Cumulative exposure to occupational physical workload factors such as lifting of heavy loads and kneeling increase the risk of long-term sickness absence more than the risk of disability retirement.[24] Furthermore, obesity[22] strengthens and leisure-time physical activity[59] reduces to some extent the adverse effect of physical workload factors on the risk of disability retirement, particularly disability retirement due to musculoskeletal disorders. In the current meta-analysis, we did not find a sufficient number of studies to conduct an additional meta-analysis to investigate an interaction between obesity and exposure to a high physical workload factor on disability retirement. Prevention of unhealthy weight gain can prevent not only excess body mass related illnesses but also disability retirement. Moreover, improvement in working conditions may also partly reduce excess body mass related disability retirement.[60]

In conclusion, excess body mass, especially obesity, is a major risk factor for disability retirement, particularly disability retirement due to musculoskeletal disorders and cardiovascular diseases. Since the prevalence of overweight and obesity is increasing globally, disease burden related to excess body mass and disability retirement consequently are projected to increase.

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Figure 1: Flow chart of the search strategy and selection of studies

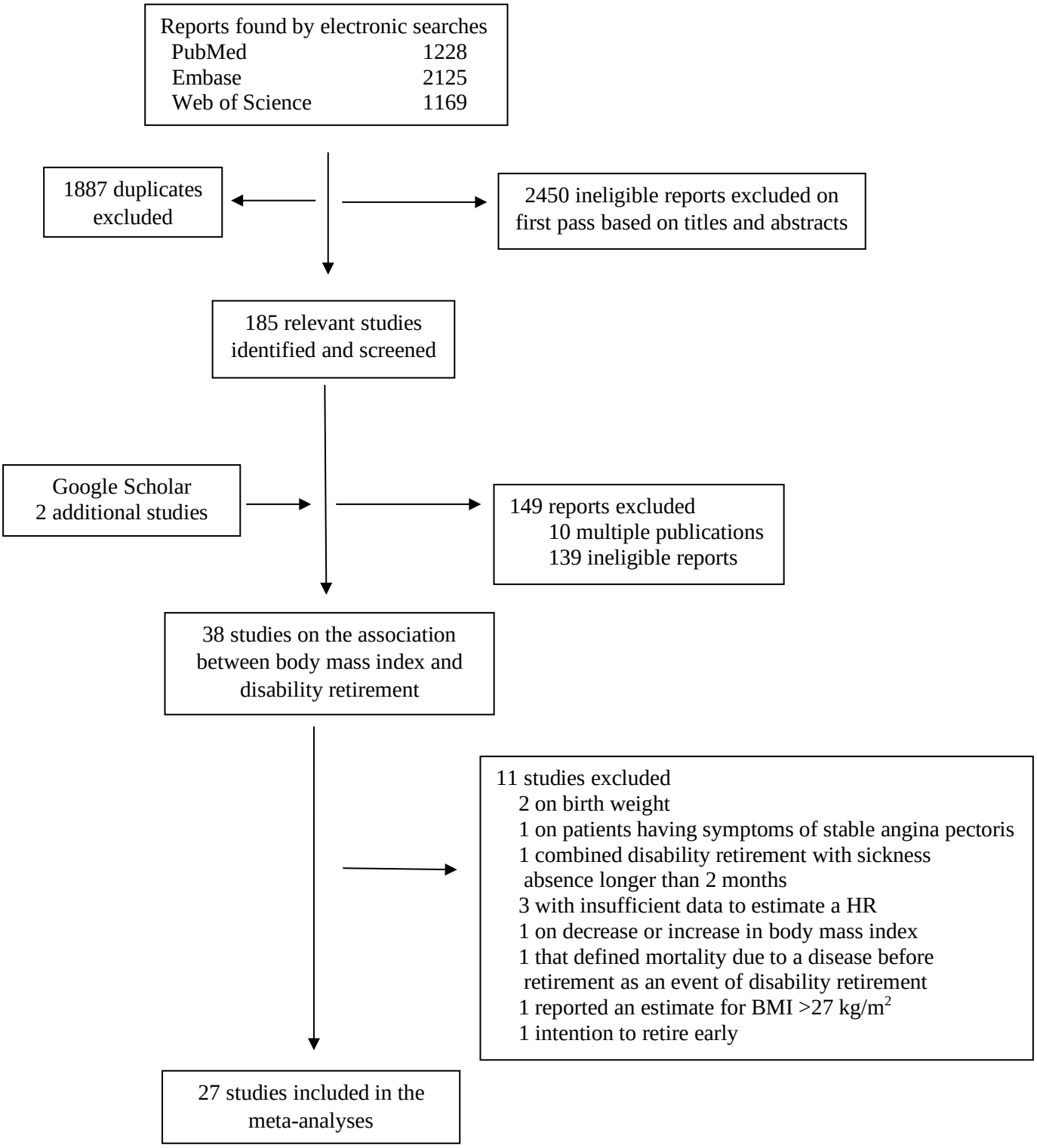


Figure 2: A meta-analysis of 19 studies on the association between body mass index and all-cause disability retirement

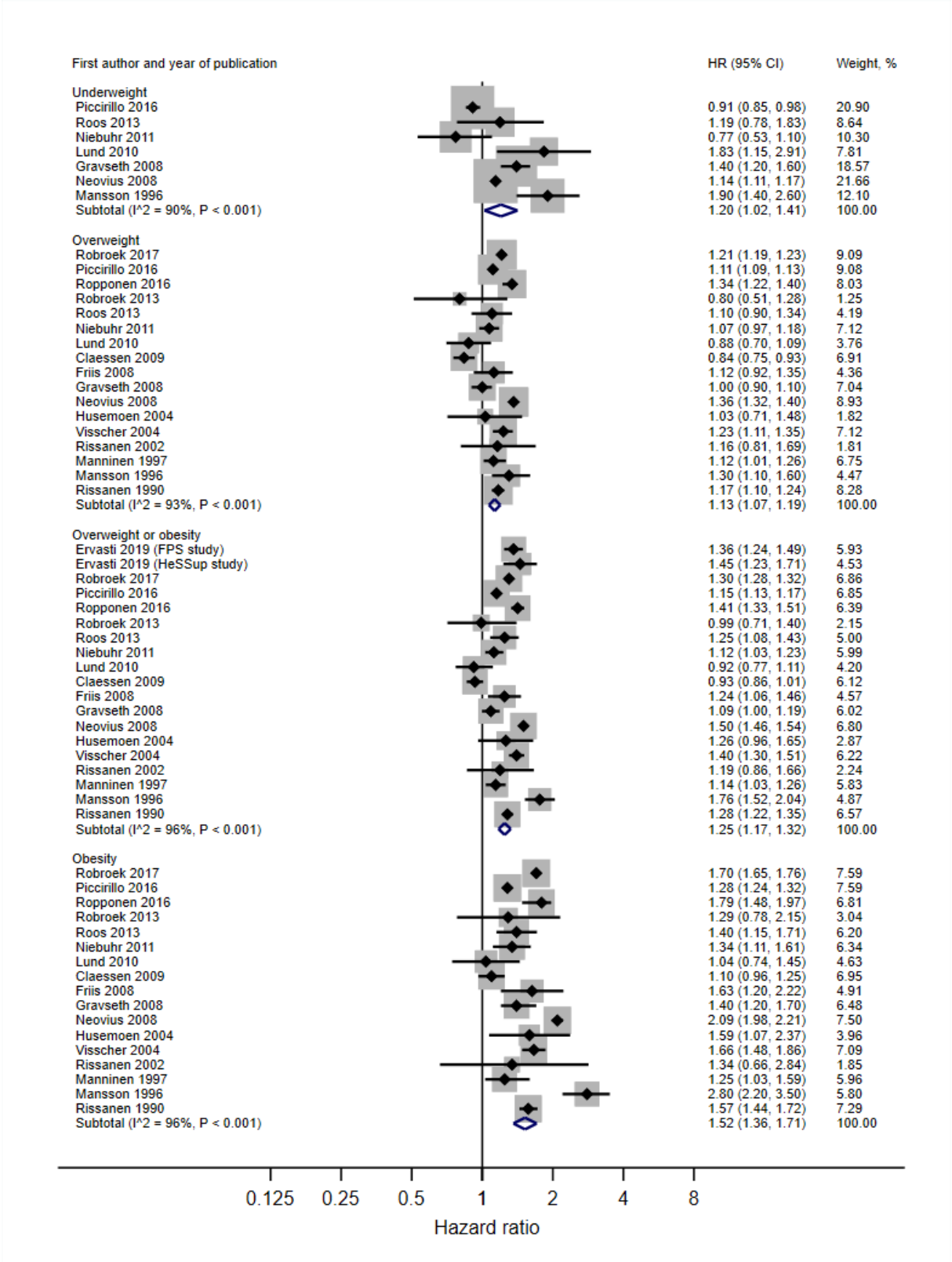


Figure 3: A meta-analysis of seven studies on the association between body mass index and disability retirement due to musculoskeletal disorders

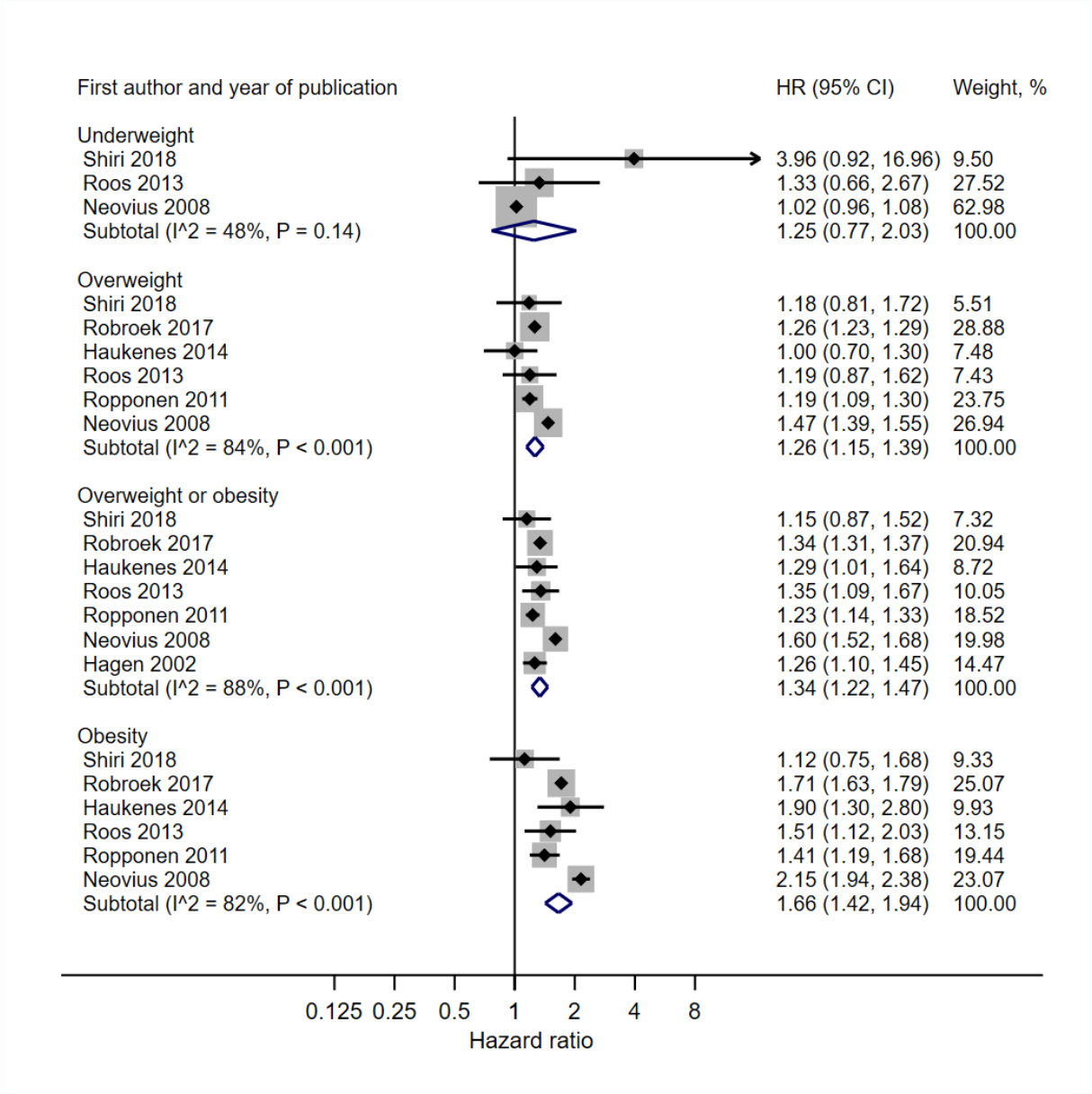
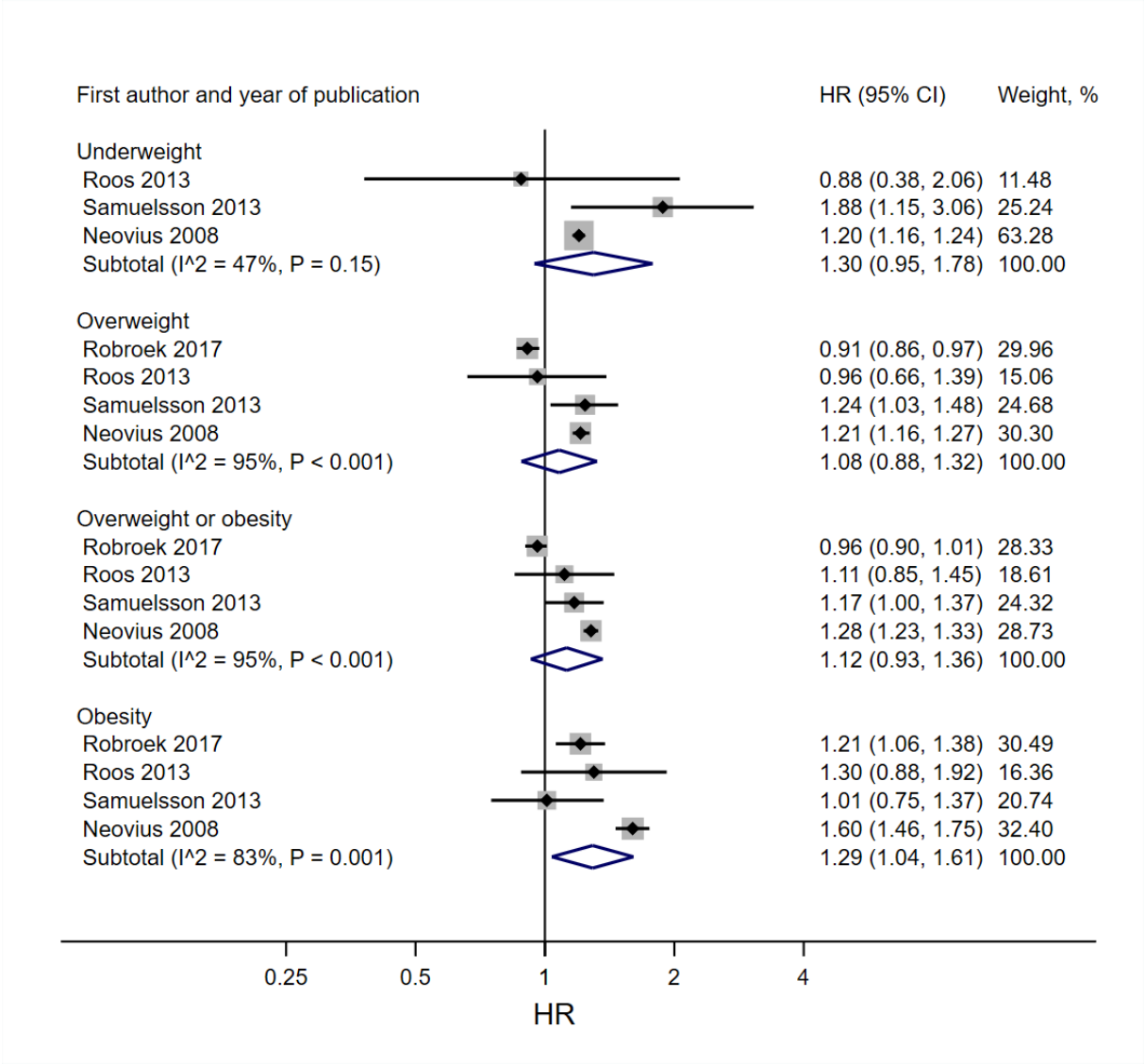


Figure 4: A meta-analysis of four studies on the association between body mass index and disability retirement due to mental disorders



Supplementary Material

Body mass index and the risk of disability retirement: A systematic review and meta-analysis

Rahman Shiri,[1] Kobra Falah-Hassani,[2] Tea Lallukka[1,3]

[1] Finnish Institute of Occupational Health, Helsinki, Finland

[2] University of Oulu and Oulu University Hospital, Oulu, Finland

[3] Department of Public Health, University of Helsinki, Helsinki, Finland

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Selection of a report from multiple publications of a single study

Several studies resulted in multiple publications. There were seven reports on overweight or obesity in relation to disability retirement from a single study. We excluded six reports[1-6] with a smaller sample or adjustment for fewer confounders and included one report[7] with adjusted estimates on all-cause and cause-specific disability retirement. Of multiple reports of single studies, we excluded reports on subsample, without reporting confidence intervals for adjusted estimates, reporting unadjusted risk estimates or reporting an estimate for change in BMI,[8-10] and included report on total study sample or adjusted estimates.[11-13] Of two reports[14 15] of a single study we included one with better definition of exposure.[14]

Studies excluded from the meta-analysis

Eleven studies were excluded from the meta-analysis: two studies on birth weight,[16 17] one on patients having symptoms of stable angina pectoris,[18] one study combined disability retirement with sickness absence longer than two months in a single qanalysis,[19] three with insufficient data to estimate a hazard ratio,[20-22] one on increase or decrease in body mass index,[10] one that defined mortality due to a disease before retirement as an event of disability retirement,[23] one study that compared BMI >27 kg/m^2 with BMI 20-27 kg/m^2,[24] and one study on intention to retire early.[25]

Supplementary Table 1: PubMed, Embase and Web of Sciences searches made on May 22, 2019

Search	Query	No of items found
PubMed		
#1	obesity [Mesh] OR obesity [Text Word] OR body weight [Mesh] OR body weight [Text Word] OR overweight [Mesh] OR overweight [Text Word] OR underweight [Mesh] OR underweight [Text Word] OR waist circumference [Mesh] OR waist circumference [Text Word] OR waist-hip ratio [Mesh] OR waist-hip ratio [Text Word] OR body mass index [Mesh] OR body mass [Text Word] OR body size [Mesh] OR body size [Text Word] OR thinness [Mesh] OR thinness [Text Word] OR waist-height ratio [Mesh] OR waist-height ratio [Text Word] OR quetelet index [Text Word]	833,780
#2	"pensions"[Mesh] OR" retirement"[Mesh] OR pension* OR retire* OR "disability benefits"	32,005
Final	#1 AND #2	1228
Embase		
#1	'body mass' OR 'waist hip ratio' OR 'obesity' OR overweight OR 'body weight' OR 'waist circumference' OR 'hip circumference' OR 'waist to height ratio' OR 'quetelet index' OR thinness OR 'underweight' OR 'body size' OR 'body height'	1,417,677
#2	'retirement'/exp OR 'pension'/exp OR pension* OR retire* OR "disability benefits"	40,310
#3	#1 AND #2	2125
Web of Sciences		
#1	obesity OR overweight OR underweight OR body weight OR waist circumference OR waist-hip ratio OR body mass OR body Size OR thinness OR waist-height ratio OR quetelet index	825,210
#2	pension* OR retire* OR "disability benefits"	38,171
Final	#1 AND #2	1169

Supplementary Table 2: Quality assessment checklist

Type of bias	Criteria definition	Classification (potential for bias)
Selection bias	Sampling method of the study population, representativeness (response rate, difference between responders and non-responders, investigate and control of variables in case of difference between responders and non-responders)	**Low:** Target population defined as representative of the general population or subgroup of the general population (specific age group, women, men, specific geographic area, and specific occupational group) and response rate is 80% or more. **Moderate:** Target population defined as somewhat representative of the general population, a restricted subgroup of the general population, response rate 60%-79%. **High:** Target population defined as "self-referred" or "self-selected"/ volunteers, response rate less than 60%.
Performance bias	Valid and reliable assessment of exposure Assessors blinded for outcome status	**Low:** Weight and height were measured. **Moderate:** Weight and height were self-reported.
Detection bias	Standard method for outcome assessment The assessor of outcome blinded to exposure status	**Low:** Register-based disability retirement. **Moderate:** Self-reported disability retirement.
Confounding	Matching two groups Stratification Statistical analysis	**Low:** Controlled for most potential confounding factors including age and sex. **Moderate:** Controlled for few potential confounding factors, including both age and sex. **High:** Not controlled for both age and sex, or controlled for less than two confounding factors.
Attrition bias	Withdrawals and drop-out rates Size of missing data	**Low:** Follow up participation rate of 80% or higher or missing data on less than 20%. **Moderate:** Follow up participation rate of 60% −79%, or missing data on 20%−40%. **High:** Follow up participation rate of less than 60%, or missing data on more than 40%.

Supplementary Table 3: Studies included in the meta-analysis

First author and year of publication	Country	Follow-up time (years)	Study population	Age range at baseline	Sex	Sample size (in analysis)	Obesity	Disability retirement	Quality assessment: Risk of bias *					Results	Adjustment for other covariates
									Selection	Performance	Detection	Confounding	Attrition		
Ervasti 2019 [26]	Finland	From 2003 until 31 December 2013. Mean follow-up 8.9 years	General working population, the Health and Social Support (HeSSup) study	Working age (20 or older). Age range not reported	Both	11 766	Self-reported weight and height. BMI was grouped into 2 levels: normal (BMI <25, reference group) and overweight (BMI ≥ 25)	Register based all-cause disability retirement	High	Moderate	Low	Low	Low	HR 1.45 (1.23-1.71)	Sex, age, socioeconomic status, smoking, alcohol consumption and physical activity
Ervasti 2019 [26]	Finland	From 2004 until 31 December 2011. Mean follow-up 6.4 years	General working population, the Finnish Public Sector (FPS) study	Working age (17 or older). Age range not reported	Both	27 008	Self-reported weight and height. BMI was grouped into 2 levels: normal (BMI <25, reference group) and overweight (BMI ≥ 25)	Register based all-cause disability retirement	Moderate	Moderate	Low	Low	Low	HR 1.36 (1.24-1.49)	Sex, age, socioeconomic status, smoking, alcohol consumption and physical activity
Shiri 2018 [27]	Finland	11 years	General working population	30-59	Both	3613	Height and weight were measured. BMI was grouped into 4 levels: underweight (BMI < 18.5), normal (BMI 18.5-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30)	Register based disability retirement due to musculoskeletal disorders	Low	Low	Low	Low	Low	HR 3.96 (CI 0.92–16.96) for underweight, 1.18 (CI 0.81–1.72) for overweight and 1.12 (CI 0.75–1.68) for obesity. Estimated HR 1.15 (0.87-1.52) for overweight or obesity	Age, sex, education, sedentary lifestyle, work demanding hands above shoulder girdle, moderate or poor physical work ability, multisite pain in the past month, pain-limiting daily activities (past 5 years), physician-diagnosed

															chronic spinal disorder, history of rheumatoid arthritis, or hip or knee osteoarthritis, history of neck or back disease treated by a doctor, and surgery for a spinal disorder or carpal tunnel syndrome
Ahola 2011 [28]	Finland	7 years	General working population	30-58	Both	3164	Height and weight were measured. BMI was grouped into 2 levels: non-obese (BMI <30), and obese (BMI ≥ 30)	Register based all-cause disability retirement	Low	Low	Low	Low	Low	Age- and sex-adjusted OR 1.53 (1.11-2.11). Fully adjusted OR 1.18 (0.81-1.72). Estimated RR 1.17 (CI 0.82-1.65)	Age, sex, education, occupational grade, depression, anxiety, alcohol use disorder, physical illness, weekly working hours, physical strain, job strain, job insecurity, smoking and leisure time physical activity
Norrbäck 2017 [29]	Sweden	Up to 16 years	General working age population	19–64	Both	50,015	Self-reported weight and height. BMI was grouped into 3 levels: normal (BMI 18.5-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30). Underweight participants	Register based all-cause and cause-specific disability retirement	Low	Moderate	Low	High	Low	Incidence rate of all-cause disability retirement 5.1 cases per 1000 person-years in normal weight participants, 7.2 cases per 1000 person-years in overweight participants and 12.3 cases per 1000 person-years in obese participants. Estimated incidence rate ratio 1.43 (1.31-	Unadjusted

							were excluded							1.57) for overweight and 2.43 (CI 2.16-2.74) for obesity for all-cause disability retirement. Incidence rate of disability retirement due to musculoskeletal disorders 2.9 cases per 1000 person-years in normal weight participants, 4.5 cases per 1000 person-years in overweight participants and 7.5 cases per 1000 person-years in obese participants. Estimated incidence rate ratio 1.54 (1.33-1.78) for overweight and 2.58 (CI 2.14-3.11) for obesity for disability retirement due to musculoskeletal disorders. Incidence rate of disability retirement due to psychiatric disorders 2.7 cases per 1000 person-years in normal weight participants, 3.1 cases per 1000 person-years in overweight participants and 4.8 cases per 1000 person-years in obese participants. Estimated incidence rate ratio 1.14 (0.97-1.33) for overweight and 1.76 (CI 1.42-2.18) for obesity for	

												Moderate		disability retirement due to psychiatric disorders. Normal weight without mobility disability (reference group) HR 1.12 (1.02,1.24) for overweight without mobility disability, 1.76 (1.54,2.01) for obesity without mobility disability, 5.85 (4.77,7.18) for normal weight with mobility disability, 6.08 (5.04,7.33) for overweight with mobility disability, and 5.17 (4.07,6.57) for obesity with mobility disability	Sex, year of birth, country of birth, highest obtained education, and other disability benefits at baseline
Robroek 2017 [30]	Sweden	Data on disability from 1980 to 2008	Construction workers	15-64	Men	328,743	Height and weight were measured. BMI was grouped into 3 levels: normal (BMI 18.5-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30). Underweight men were excluded	Register based all-cause and cause-specific disability retirement	Low	Low	Low	Moderate	Low	All-cause disability retirement HR 1.21 (CI 1.19–1.23) for overweight and 1.70 (CI 1.65–1.76) for obesity. Estimated HR 1.30 (CI 1.28- 1.32) for overweight or obesity. Disability due to musculoskeletal disorders HR 1.26 (CI 1.23–1.29) for overweight and 1.71 (CI 1.63–1.79) for obesity. Estimated HR 1.34 (CI 1.31-1.37) for overweight or obesity.	Age, smoking, and physical workload

														Disability due to mental disorders HR 0.91 (CI 0.86–0.97) for overweight and 1.21 (CI 1.06–1.38) for obesity. Estimated HR 0.96 (CI 0.90-1.01) for overweight or obesity. Disability due to cardiovascular diseases HR 1.47 (CI 1.40–1.54) for overweight and 2.30 (CI 2.13–2.50) for obesity	
Haukenes 2014 [31]	Norway	5 years	All individuals in Hordaland county born in 1953–57	40–46	Both	16422	Height and weight were measured. BMI was grouped into 4 levels: underweight (BMI < 18.5), normal (BMI 18.5-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30). No-one was underweight	Register based disability retirement due to musculoskeletal disorders	Moderate	Low	Low	Moderate	Low	HR 1.0 (CI 0.7–1.3) for overweight and 1.9 (CI 1.3–2.8) for obesity. Estimated HR 1.29 (CI 1.01- 1.64) for overweight or obesity	Age and sex
Canivet 2013 [32]	Sweden	12 years	The working general population of the city of Malmö	45-65	Both	6540 (3181 men and 3359 women)	Height and weight were measured. BMI was grouped into 2 levels: non-obese (BMI <30), and obese (BMI ≥ 30)	Register based all-cause disability retirement	High	Low	Low	Low	Low	Age-adjusted HR 1.7 (1.3–2.2) for men and 1.6 (1.3–2.0) for women. Estimated age- and sex-adjusted HR 1.64 (CI 1.39-1.94). Fully adjusted HR 1.7 (1.1–2.6) for healthy	Age, socioeconomic position, smoking, alcohol consumption, high strain, and stress from outside the workplace

														men at baseline and 1.5 (1.1–2.0) for unhealthy men at baseline. Fully adjusted HR 1.6 (1.1–2.5) for healthy women at baseline and 1.3 (1.02–1.7) for unhealthy women at baseline. Estimated fully adjusted HR 1.56 (CI 1.22-2.00) for men and 1.38 (CI 1.11- 1.71) for women and 1.46 (CI 1.24- 1.71) for both sexes combined	
Robroek 2013 [12]	11 European countries (Sweden, Denmark, the Netherlands, Belgium, Germany, Austria, Switzerland, France, Italy, Spain, and Greece)	4 years	The sampling designs varied from simple random selection of households to complicated multistage designs	Working age ≥50 years	Both	4923	Self-reported weight and height. BMI was grouped into 3 levels: normal (BMI <25, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30)	Self-reported all-cause disability retirement	Moderate	Moderate	Moderate	Low	Moderate	HR 0.80 (CI 0.51–1.28) for overweight and 1.29 /CI 0.78–2.15) for obesity. Estimated HR 0.99 (CI 0.71-1.40) for overweight or obesity	Age, sex, educational level, cohabitation status, lack of physical activity, excessive alcohol intake, self-rated health, low job control and low rewards
Roos 2013 [14]	Finland	Mean follow-up time 7.8 years	The employees of the City of Helsinki	40-60	Both	6542 (1411 men and 5131 women)	Self-reported weight and height. BMI was grouped into 5 levels: <20 (underweight), 20–24.9 (normal weight, reference group), 25–	Register based all-cause disability retirement, disability retirement due to musculoskeletal disorders, disability	Moderate	Moderate	Low	Low	Low	All-cause disability retirement Both sexes combined HR 1.19 (CI 0.78–1.83) for underweight, 1.10 (CI 0.90–1.34) for overweight, 1.27 (CI 1.00–1.63) for obese and 1.68 (CI 1.22–2.35) for morbid obesity.	Age, gender, diagnosed diseases (cardiovascular diseases, musculoskeletal disorders, mental disorders, diabetes, eating disorders,

							29.9 (overweight), 30–34.9 (obese), and ≥35 (morbid obese)	retirement due to mental disorders						Estimated HR 1.40 (CI 1.15-1.71) for obesity and 1.245 (CI 1.08-1.43) for overweight or obesity. Men HR 1.45 (CI 0.92–2.30) for overweight, 0.95 (CI 0.49–1.84) for obese and 1.19 (CI 0.51–2.78) for severely obese. No estimate for underweight. Estimated HR 1.04 (CI 0.61-1.74) for obesity. Women HR 1.29 (CI 0.84–1.99) for underweight, 1.02 (CI 0.82–1.27) for overweight, 1.33 (CI 1.02–1.74) for obese and 1.73 (CI 1.20–2.49) for severely obese. Estimated HR 1.46 (CI 1.17-1.81) for obesity. Disability retirement due to musculoskeletal disorders Both sexes combined HR 1.33 (CI 0.66–2.67) for underweight, 1.19 (CI 0.87–1.62) for overweight, 1.35 (CI 0.92–1.96) for obese, and 1.79 (CI 1.12–2.87) for severely obese. Estimated HR 1.51 (CI 1.12-2.03) for obesity. Estimated HR 1.35 (CI 1.09-1.67) for overweight or obesity.	cancer), physical and mental functioning, and working conditions (shift work, physical working conditions, psychosocial stress at work)

														Disability retirement due to mental disorders Both sexes combined HR 0.88 (CI 0.38–2.06) for underweight, 0.96 (CI 0.66–1.39) for overweight, 1.16 (CI 0.72–1.87) for obese, and 1.63 (CI 0.83–3.21) for severely obese. Estimated HR 1.30 (CI 0.88-1.92) for obesity, and 1.11 (CI 0.85-1.45) for overweight or obesity	
Samuelsson 2013 [13]	Sweden	Median 10 years (1998–2008)	All twins born in Sweden in 1925–1958	41-64	Both	28,613	Self-reported weight and height. BMI was grouped into 4 levels: underweight (BMI < 18.5), normal (BMI 18.5-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30)	Register based disability retirement due to mental disorders	Moderate	Moderate	Low	Low	Low	Age- and gender-adjusted HR 2.45 (CI 1.50-3.98) for underweight, 1.25 (CI 1.05-1.50) for overweight and 1.38 (CI 1.03-1.84) for obesity. Full model HR 1.88 (CI 1.15-3.06) for underweight, 1.24 (CI 1.03-1.48) for overweight and 1.01 (CI 0.75-1.37) for obesity. Estimated HR 1.17 (CI 1.00-1.37) for overweight or obesity	Age, gender, education, marital status, severity of diseases, leisure-time physical activity, smoking, alcohol consumption and self-rated health
Ropponen 2011 [33]	Finland	30 years	Twins	18-64	Both	24,043 (12214 men and 11829 women)	Self-reported weight and height.1-unit increase	Register based disability retirement due to musculoskeletal disorders	Low	Moderate	Low	Low	Low	HR 1.05 (CI 1.02-1.07) for men and 1.02 (CI 1.00-1.05) for women s. Estimated RR 1.035 (CI 1.018-1.053) for both sexes combined	Age, education, social class. smoking, alcohol consumption, any chronic disease, musculoskeletal

														for 1-unit increase in BMI. Estimated HR 1.28 (CI 1.10-1.40) for overweight and 1.63 (CI 1.22-1.97) for obesity for men. Estimated HR 1.10 (CI 1.00-1.28) for overweight and 1.22 (CI 1.00-1.63) for women. Estimated HR 1.19 (CI 1.09-1.30) for overweight and 1.41 (CI 1.19-1.68) for obesity for both sexes combined. Estimated HR 1.23 (CI 1.14-1.33) for overweight or obesity for both sexes combined	pain, and use of analgesic
Ropponen 2016 [34]	Finland	23 years	Twins	18-64	Both	17,169	Self-reported weight and height. 1-unit increase in BMI	Register based all-cause disability retirement	Low	Moderate	Low	Low	Low	HR 1.06 (1.04-1.07). Estimated HR 1.34 (CI 1.22-1.40) for overweight and 1.79 (CI 1.48-1.97) for obesity. Estimated HR 1.415 (CI 1.33-1.51) for overweight or obesity	Age, sex, socioeconomic status, education, marital status, leisure-time physical activity, and musculoskeletal pain
Lund 2010 [11]	Denmark	Up to 16 years, 1990–2006	A representative sample of working population, the Danish Work Environme	18-59	Both	8287 (4203 men and 4084 women)	Self-reported weight and height. BMI was grouped into 4 levels: underweight (BMI < 18.5), normal (BMI	Register based all-cause disability retirement	Moderate	Moderate	Low	Moderate	Low	Men HR 2.42 (CI 0.76–7.72) for underweight, 0.67 (CI 0.49–0.93) for overweight and 0.84 (CI 0.52–1.37) for obesity. Women	Age, work environment and general health

			nt Cohort Study				18.5-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30)							HR 1.74 (CI 1.05–2.88) for underweight, 1.11 (CI 0.82–1.50) for overweight and 1.25 (CI 0.79–1.97) for obesity. Both sexes combined HR 1.834 (CI 1.155-2.912) for underweight, 0.875 (CI 0.703-1.090) for overweight and 1.037 (0.744-1.445) for obesity. Estimated HR 0.92 (CI 0.77 -1.11) for overweight or obesity	
Claessen 2009 [35]	Germany	Mean follow-up 10.8 years	Construction workers (bricklayers, painters, labourers plumbers, carpenters, plasterers)	25–59	Men	16,875	Height and weight were measured. BMI was grouped into 7 levels: <20.0, 20.0–22.4 (ref. group), 22.5–24.9, 25.0–27.4, 27.5–29.9, 30.0–34.9, ≥35.0	Register based all-cause disability retirement	Moderate	Low	Low	Moderate	Low	HR 1.09 (0.80 to 1.48) for BMI <20, 0.79 (0.69 to 0.92) for BMI 25.0–27.4, 0.89 (0.76 to 1.03) for BMI 27.5–29.9, 0.92 (0.78 to 1.07) for 30.0–34.9, and 1.56 (1.25 to 1.96) for ≥35.0. Estimated HR 0.836 (CI 0.753- 0.928) for overweight, 1.095 (CI 0.963-1.247) for obesity and 0.930 (CI 0.858-1.009) for overweight or obesity	Age, nationality, smoking status and alcohol consumption
Kamaleri 2009 [36]	Norway	14 years	Four age groups in the municipality of Ullensaker	20-52	Both	1354	Self-reported weight and height. BMI was grouped into 3 levels: <25 kg/m^2, 25-30 and ≥30 kg/m^2	Self-reported permanent or long-term social security benefits due to illness in 2004	Moderate	Moderate	Moderate	High	Moderate	Prevalence of disability was 10.9% in underweight or normal weight, 17.4% in overweight and 28.1% in obese participants. Estimated RR 1.597 (CI 1.172-2.175) for overweight and 2.586	Unadjusted

														(1.682- 3.978) for obesity	
Friis 2008 [37]	Denmark	9 years	Nurses of the Danish Nurse Association	Above the age of 44	Women	12,028	Self-reported weight and height. BMI was grouped into 3 levels: <25 kg/m^2, 25-30 and ≥30 kg/m^2	Register based all-cause disability retirement	Low	Moderate	Low	Low	Low	Unadjusted HR 1.18 (CI 0.99–1.41) for overweight and 1.59 (CI 1.18–2.13) for obesity. Adjusted HR 1.12 (CI 0.92–1.35) for overweight and 1.63 (CI 1.20–2.22) for obesity. Estimated HR 1.244 (CI 1.057-1.464) for overweight or obesity	Working schedule, working area, influence at work, physical demands at work, leisure time physical activity, smoking, marital status and spouse's socioeconomic status and own gross income
Gravseth 2008 [38]	Norway	4 to 13 years, men born in 1967–1976 with follow-up from age 23 years until 2003	Boys live born in Norway in 1967–76 (registered by the Medical Birth Registry of Norway)	24–36	Men	302,330	Height and weight were measured at age 18-19. BMI was grouped into 4 levels: underweight (BMI < 18.5), normal (BMI 18.5-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30)	Register based all-cause disability retirement	Low	Low	Low	Low	Low	HR 1.4 (CI 1.2–1.6) for underweight, 1.0 (CI 0.9–1.1) for overweight and 1.4 (CI 1.2–1.7) for obesity. Estimated HR 1.087 (CI 0.997-1.186) for overweight or obesity	Year of birth, birth order, birth weight (standardized for birth order), height, childhood disease benefit, maternal marital status, maternal and paternal disability, parental education, educational level, Intellectual performance, and Mental function
Neovius 2008 [7]	Sweden	Median follow-up time 23.8 years (from	Men born between 1951 and 1976 and underwent military conscriptio	17-20	Men	1,191,027	Height and weight were measured. BMI was grouped into 5 levels:	Register based all-cause and cause-specific disability retirement	Low	Low	Low	Low	Low	All-cause disability retirement HR adjusted for year of conscription testing 1.28 (CI 1.25–1.31) for underweight, 1.31 (CI	Age at testing, testing center, year of testing, municipality (urban, semi-urban, rural),

		1971 to 2007)	n induction tests between 1969 and 1994				underweight (BMI < 18.5), normal (BMI 18.5-24.9, reference group), over-weight (BMI 25-29.9), obese (BMI 30-34.9) and morbid obese (BMI ≥ 35)						1.27–1.34) for overweight, 1.81 (CI 1.70–1.91) for obese, and 3.03 (CI 2.72–3.38) for morbid obese. Fully adjusted HR 1.14 (CI 1.11–1.17) for underweight, 1.36 (CI 1.32–1.40) for overweight, 1.87 (CI 1.76–1.99) for obese, and 3.04 (CI 2.72–3.40) for morbid obese. Estimated HR 2.09 (CI 1.98-2.21) for obese or morbid obese and 1.50 (CI 1.46-1.54) for overweight or obesity ((BMI ≥25). Disability retirement due to musculoskeletal disorders. Fully adjusted HR 1.02 (CI 0.96–1.08) for underweight, 1.47 (CI 1.39–1.55) for overweight, 2.15 (CI 1.94–2.38) for obese or morbid obese. Estimated HR 1.60 (CI 1.52-1.68) for overweight or obesity. Disability retirement due to psychiatric disorders. Fully adjusted HR 1.20 (CI 1.16–1.24) for underweight, 1.21 (CI 1.16–1.27) for overweight, 1.60 (CI 1.46–1.75) for obesity or morbid obesity.	socioeconomic position (white collar, blue collar, self-employed and other), and muscular strength (hand grip, arm flexion, leg extension)

														Estimated HR 1.28 (CI 1.23-1.33) for overweight or obesity. Disability retirement due to circulatory disorders. Fully adjusted HR 0.99 (CI 0.86–1.14) for underweight, 2.06 (CI 1.82–2.34) for overweight and 3.51 (CI 2.79–4.40) for obesity or morbid obesity	
Harkonmäki 2007 [39]	Finland	5 years (1998-2003)	General working age population	40-54	Both	8817	Self-reported weight and height. BMI was grouped into 2 levels: <30 kg/m^2 and ≥30 kg/m^2	Self-reported all-cause disability retirement	High	Moderate	Moderate	Low	Low	Age- and gender-adjusted OR 2.21 (CI 1.70-2.90). Full model OR 1.58 (CI 1.18-2.12). Estimated age- and gender-adjusted RR 2.12 (CI 1.66-2.71). Estimated full model RR 1.55 (CI 1.17-2.04)	Age, gender, socioeconomic status, smoking, alcohol intoxication once a week or more, depression, and use of drugs for somatic diseases (analgesics, antihypertensive and heart drugs for >6 months during the previous year)
Husemoen 2004 [40]	Denmark	6 years	A random sample of people from the Copenhagen area	20-67	Both	9053 (5623 men and 3430 women)	Self-reported weight and height. BMI was grouped into 4 levels: <20 (ref. group), 20–24, 25–30, >30	Register based all-cause disability retirement from 1980 to 1985	Moderate	Moderate	Low	Moderate	Low	Women ORs 0.70 (CI 0.44–1.09), 0.72 (0.44–1.17) and 1.21 (0.69–2.13). Men ORs 0.50 (0.28–0.90), 0.51 (0.28–0.93) and 0.77 (0.39–1.50). Estimated ORs using normal weight as a reference group. Men	Sex-specific analysis adjusted for age

														OR 1.02 (CI 0.55-1.88) for overweight and 1.54 (CI 0.77-3.06) for obesity. Women OR 1.03 (CI 0.62-1.69) for overweight and 1.73 (CI 0.97-3.07) for obesity. Estimated RRs Men RR 1.02 (CI 0.56-1.81) for overweight and 1.50 (CI 0.78-2.79) for obesity. Women RR 1.03 (CI 0.64-1.61) for overweight and 1.65 (CI 0.97-2.68) for obesity. Estimated RRs for both sexes combined. RR 1.03 (CI 0.71-1.48) for overweight and 1.59 (CI 1.07-2.37) for obesity. Estimated RR 1.26 (CI 0.96-1.65) for overweight or obesity	
Visscher 2004 [41]	Finland	15 years	A random sample of the general population	20-64	Both	17,235 (8908 men and 8327 women)	Height and weight were measured. BMI was grouped into 4 levels: underweight (BMI < 18.5), normal (BMI 18.5-24.9, reference group), over-	Register based all-cause disability retirement	Low	Low	Low	Low	Low	Men RR 1.1 (CI 1.0-1.3) for overweight and 1.7 (CI 1.5-2.0) for obesity. Women RR 1.4 (1.2-1.6) for overweight and 1.6 (1.4-2.0) for obesity. Estimated RR for both sexes combined.	Age, educational level, geographic region, alcohol use, and smoking. Subjects with the condition at baseline were excluded from the analyses

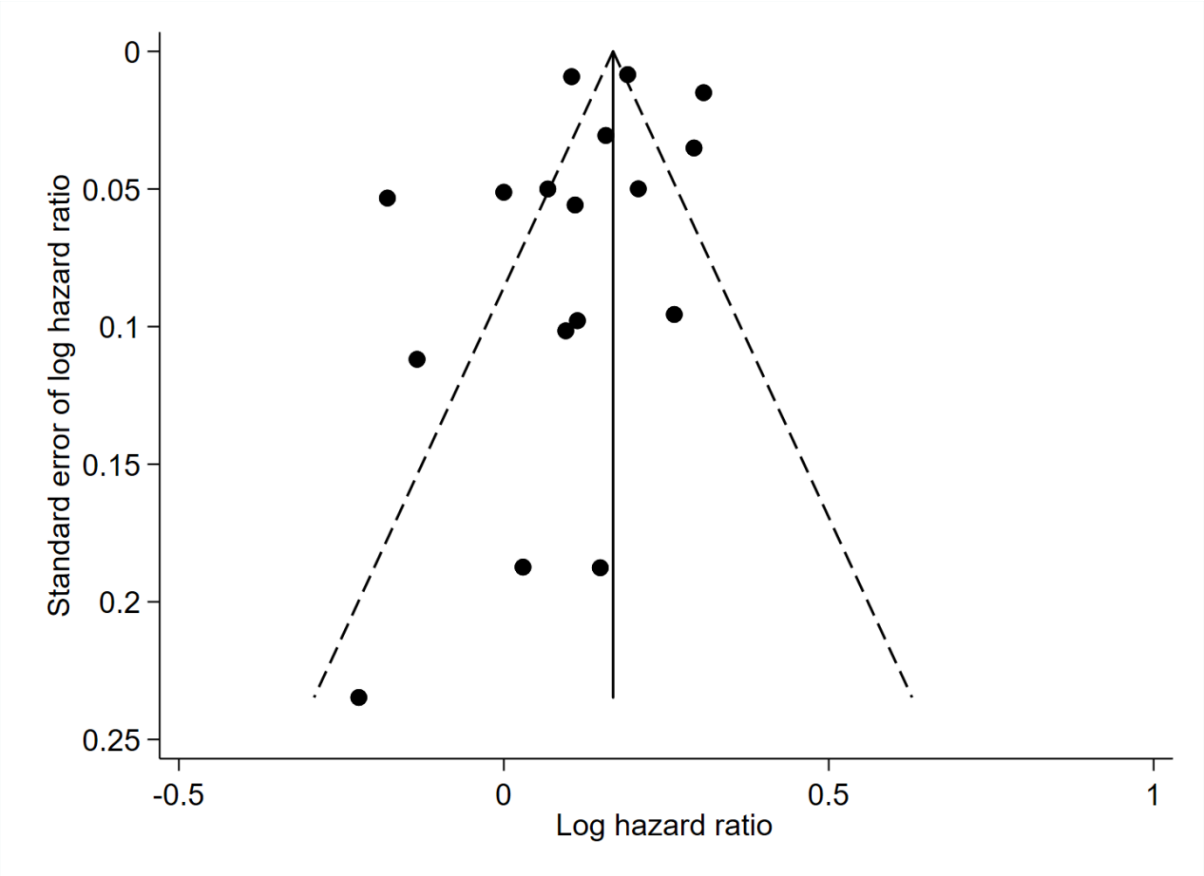
							weight (BMI 25-29.9), and obese (BMI ≥ 30)							RR 1.23 (CI 1.11 - 1.35) for overweight and 1.66 (1.48-1.86) for obesity. Estimated RR 1.40 (CI 1.30-1.51) for overweight or obesity	
Hagen 2002 [42]	Norway	7 years	The general working population	25-59	Both	34,754	Height and weight were measured. BMI was grouped into 4 levels: <24.1 reference group), 24.1-26.3, 26.4-28.6 and >28.6	Register based disability retirement due to back pain	Moderate	Low	Low	Low	Low	OR adjusted for age and gender 1.1 (CI 0.8–1.2) for BMI 24.1-26.3, 1.4 (CI 1.1–1.7) for BMI 26.4-28.6, and 1.8 (CI 1.4–2.3) for BMI >28.6. Estimated RR adjusted for age and gender 1.1 (CI 0.8–1.2) for BMI 24.1-26.3, 1.39 (CI 1.10–1.68) for BMI 26.4-28.6, and 1.77 (CI 1.39–2.24) for BMI >28.6. Fully adjusted OR 1.0 (CI 0.8–1.3) for BMI 24.1-26.3, 1.3 (CI 1.0–1.6) for BMI 26.4-28.6, and 1.6 (CI 1.2–2.0) for BMI >28.6. Estimated fully adjusted RR 1.00 (CI 0.80–1.29) for BMI 24.1-26.3, 1.29 (CI 1.00–1.58) for BMI 26.4-28.6, and 1.58 (CI 1.19–1.96) for BMI >28.6. Estimated RR 1.26 (CI 1.10-1.45) for BMI > 24 kg/m^2 and 1.42 (CI 1.19-1.68) for BMI >26.3 kg/m^2	Age, gender, physically demanding work, smoking, perceived general health, diabetes, angina pectoris, and worn out or healthy/strong

Rissanen 2002 [43]	Finland	Mean follow-up 12 years	A representative sample of the general population	30-64	Both	535	Height and weight were measured. 1 SD increase in BMI (3.7 kg/m^2)	Register based all-cause disability retirement	High	Low	Low	Moderate	Low	RR 1.12 (CI 0.86–1.46) for 1-SD increase in BMI. Estimated RR 1.03 (CI 0.96-1.11) for 1-unit increase in BMI. Estimated RR 1.16 (CI 0.81-1.69) for overweight and 1.34 (CI 0.66-2.84) for obesity. Estimated RR 1.19 (CI 0.86-1.66) for overweight or obesity	Age and sex
Mansson 2001 [44]	Sweden	11 years	Five complete birth-year (1926-1930) cohorts of middle-aged male residents of Malmö	95% were 47-49 years	Men	5313	Height and weight were measured. BMI was grouped into 2 levels: <30 kg/m^2 and ≥30 kg/m^2	Register based all-cause disability retirement	Moderate	Low	Low	Moderate	Low	Unadjusted HR 2.2 (CI 1.7-2.7). Adjusted HR 2.0 (CI 1.6-2.5) for obesity vs. non-obesity	Occupation and self-rated health
Mansson 1996 [45]	Sweden	11 years	Five complete birth-year (1926-1930) cohorts of middle-aged residents of Malmö	95% were 47-49 years	Men	5926	Height and weight were measured. BMI was grouped into 4 levels: underweight (BMI < 20), normal (BMI 20-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30)	Register based all-cause disability retirement	Moderate	Low	Low	Moderate	Low	HR 1.9 (CI 1.4–2.6) for underweight, 1.3 (CI 1.1–1.6) for overweight and 2.8 (CI 2.2–3.5) for obesity. Estimated HR 1.76 (CI 1.52-2.04) for overweight or obesity	Smoking

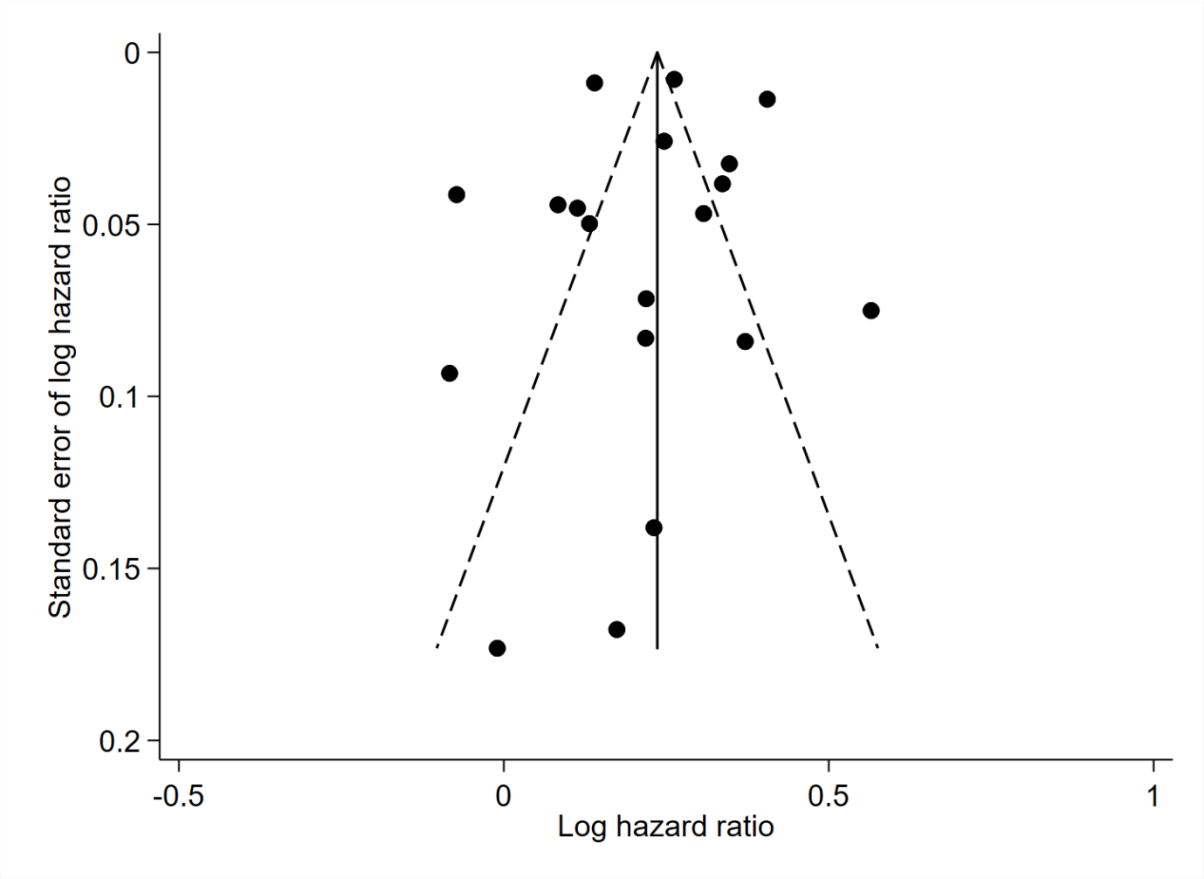
Manninen 1997 [46]	Finland	10 years	A representative sample of farmers	18-64	Both	8655	Self-reported weight and height	Register based all-cause disability retirement	Low	Moderate	Low	Moderate	Low	HR 1.08 (CI 1.01-1.15) for 1 SD (3.5 kg/m^2) increase. Estimated HR for 1-unit increase in BMI 1.022 (CI 1.003-1.048). Estimated HR 1.116 (1.014-1.262) for overweight and 1.246 (CI 1.029-1.593) for obesity. Estimated RR 1.141 (CI 1.035-1.258) for overweight or obesity	Age, sex, smoking and psychological distress score
Rissanen 1990 [47]	Finland	Mean follow-up 11 years	A representative sample of the general population	18-64	Both	31,129 (19,076 men and 12,053 women)	Height and weight were measured. BMI was grouped into 6 levels: <22.5 (ref. group), 22 5-24-9, 25-0-27 4, 27-5-29-9, 300-324, ≥32 5	Register based all-cause disability retirement	Low	Low	Low	Moderate	Low	All-cause disability retirement Men RRs 1.0 (CI 0.9-1.2), 1.1 (CI 1.0-1.2), 1.2 (CI 1.1-1.4), 1.4 (CI 1.2-1.6) and 1.8 (CI 1.4-2.2). Women RRs 1.2 (1.0-1.4), 1.5 (CI 1.3-1.7), 1.5 (1.3-1.8), 1.9 (1.6-2.3) and 2.1 (CI 1.7-2.5). Estimated RRs for women using normal weight as a reference group 1.25 (1.09-1.43), 1.25 (1.06-1.48), 1.58 (1.32-1.91) and 1.75 (1.44-2.13). All-cause disability Men RR 1.135 (CI 1.05-1.22) for overweight	Age, geographical region, smoking, and occupation

														and 1.51 (CI 1.33-1.70) for obesity. Women RR 1.25 (CI 1.12-1.39) for overweight and 1.66 (CI 1.45-1.90) for obesity. Both sexes combined RR 1.17 (CI 1.10-1.24) for overweight, 1.57 (CI 1.44- 1.72) for obesity, and 1.28 (CI 1.22-1.35) for overweight or obesity	
Nested case control studies															
Piccirillo 2016 [48]	The United State	Cases during a 10-year period, between October 1, 2002 and September 30, 2012	Active duty enlisted Army personnel. Cases were individuals who received a disability retirement during the study period and controls were randomly selected active duty enlisted soldiers with no history of disability evaluation	89% were younger than 30 years	Both	122 838 (40,946 cases and 81,892 controls)	Height and weight were measured. BMI was grouped into 4 levels: underweight (BMI < 18.5), normal (BMI 18.5-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30)	Recorded all-cause disability retirement	Low	Low	Low	Moderate	Low	Unadjusted OR 0.93 (CI 0.86-0.99) for underweight, 1.19 (CI 1.16-1.21) for overweight and 1.42 (CI 1.38-1.47) for obesity Adjusted OR 0.91 (CI 0.85-0.98) for underweight, 1.11 (CI 1.09-1.13) for overweight and 1.28 (CI 1.24-1.32) for obesity. Estimated OR 1.15 (CI 1.13-1.17) for overweight or obesity	Matched for enlistment year and sex. Adjusted for age, race, marital status, education, and deployment status

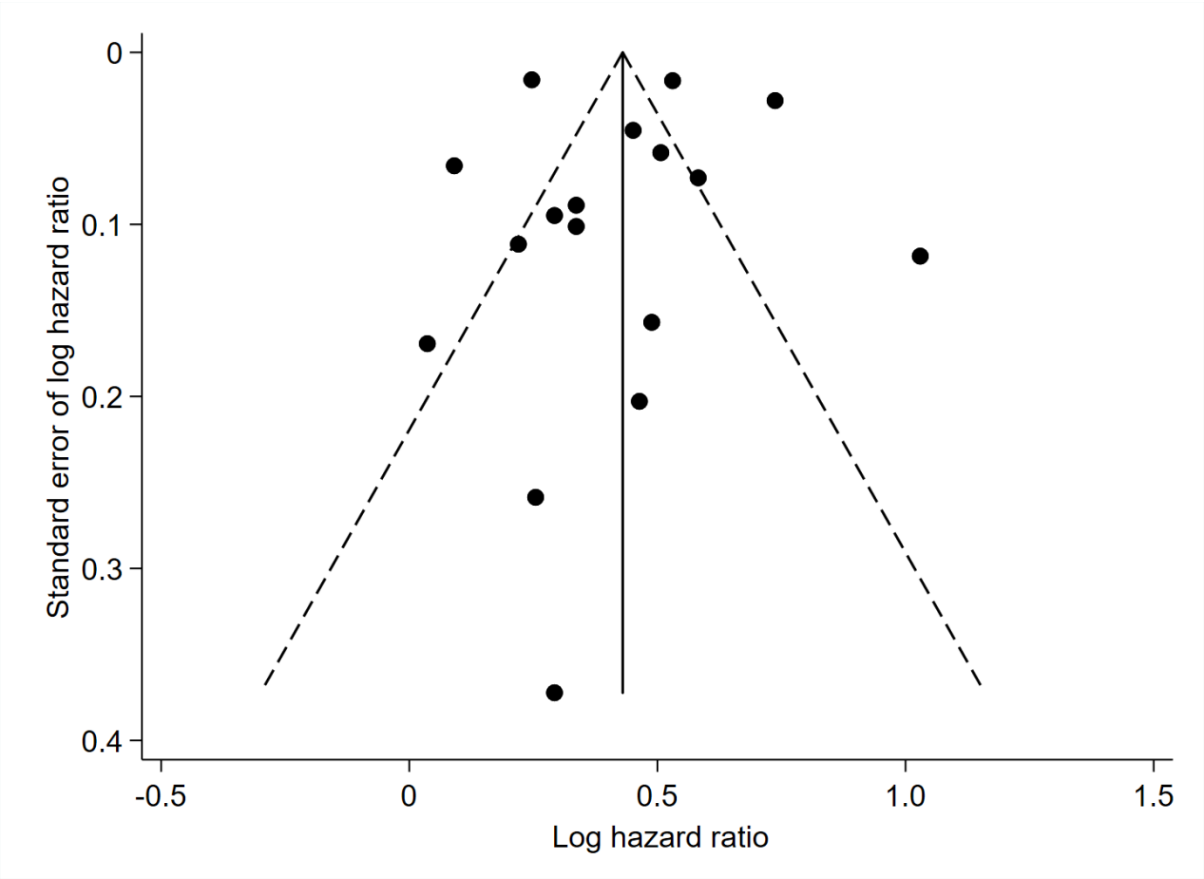
Niebuhr 2011 [49]	The United State	Cases during 1997 and 2006	Active duty Army soldiers. Cases were individuals who received a disability retirement during the study period and controls were individuals who were not granted a disability retirement	96% were younger than 30 years	Both	2453 cases and 12,265 controls	Height and weight were measured at age 18-19. BMI was grouped into 4 levels: underweight (BMI < 18.5), normal (BMI 18.5-24.9, reference group), over-weight (BMI 25-29.9), and obese (BMI ≥ 30)	Recorded temporary or permanent all-cause disability retirement	Low	Low	Low	Moderate	Low	OR 0.77 (CI 0.53-1.10) for underweight, 1.07 (CI 0.97-1.18) for overweight and 1.34 (CI 1.11-1.61) for obesity. Estimated OR 1.12 (CI 1.03-1.23) for overweight or obesity	Cases were matched with controls by the year of military entry. Estimates were adjusted for age, sex, education, race/ethnicity, deployment and medical qualification status



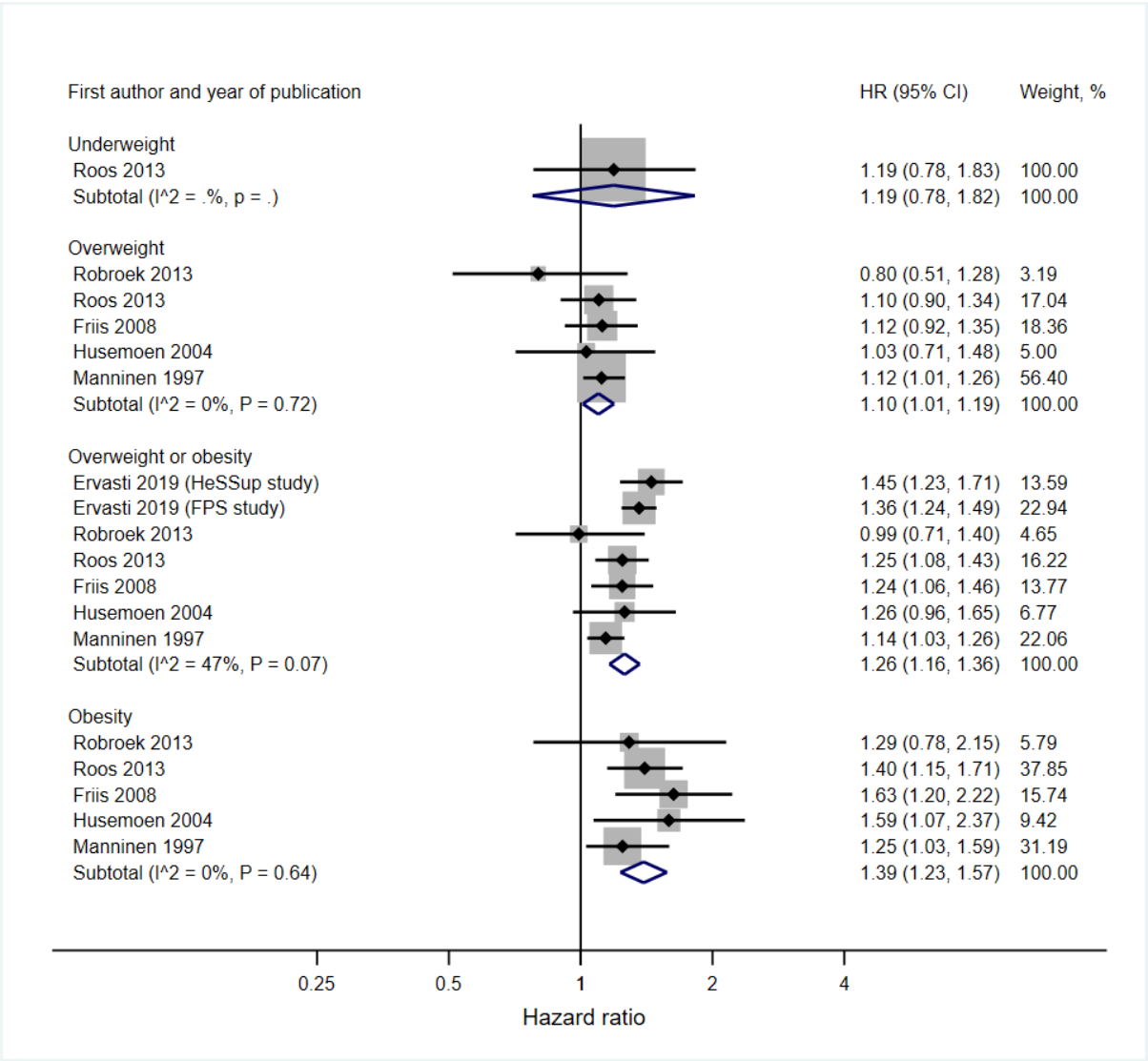
Supplementary Figure 1: Funnel plot of 17 studies on the association between overweight and all-cause disability retirement (P for Egger test=0.43)



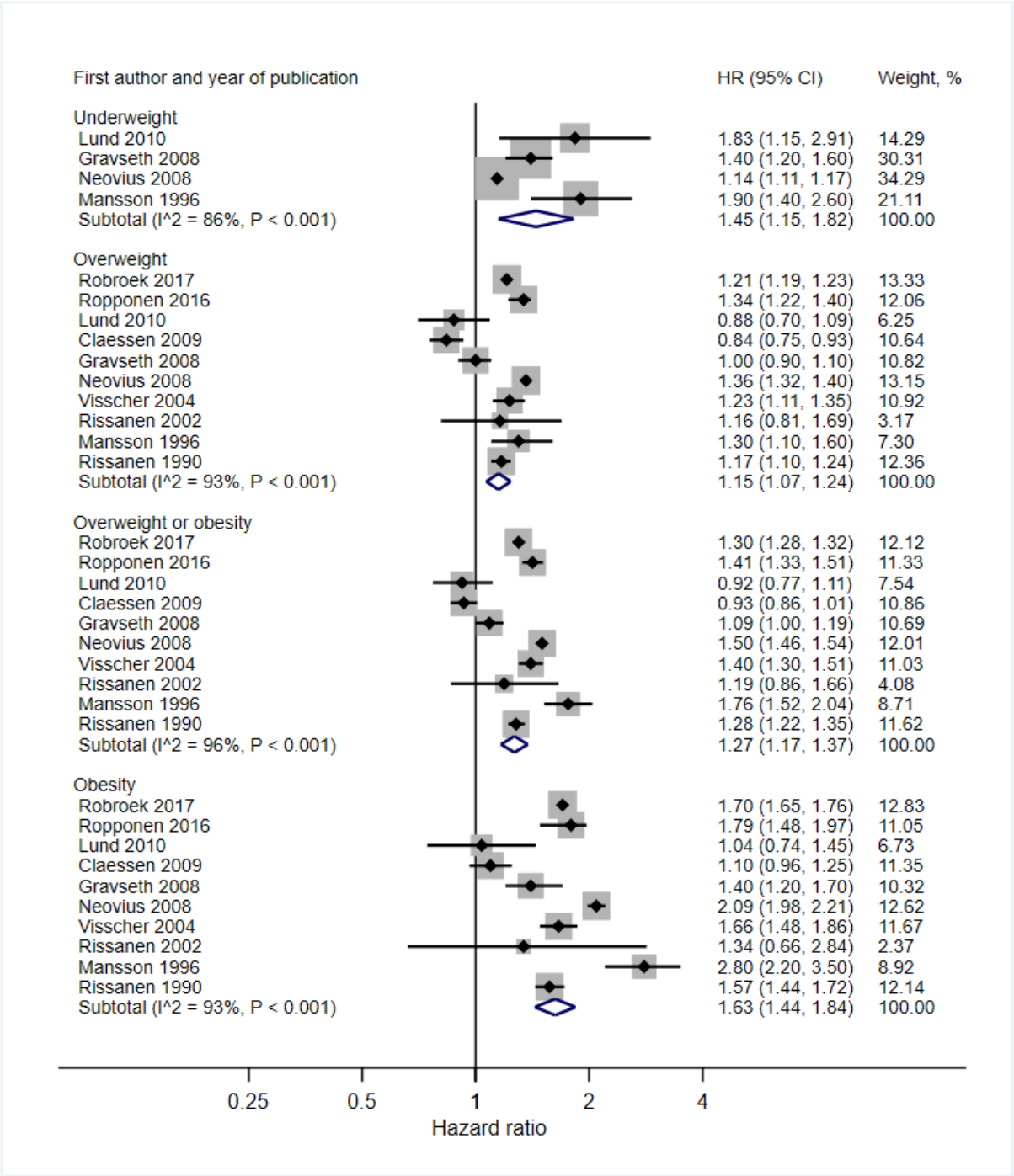
Supplementary Figure 2: Funnel plot of 19 studies on the association between overweight or obesity and all-cause disability retirement (P for Egger test=0.87)



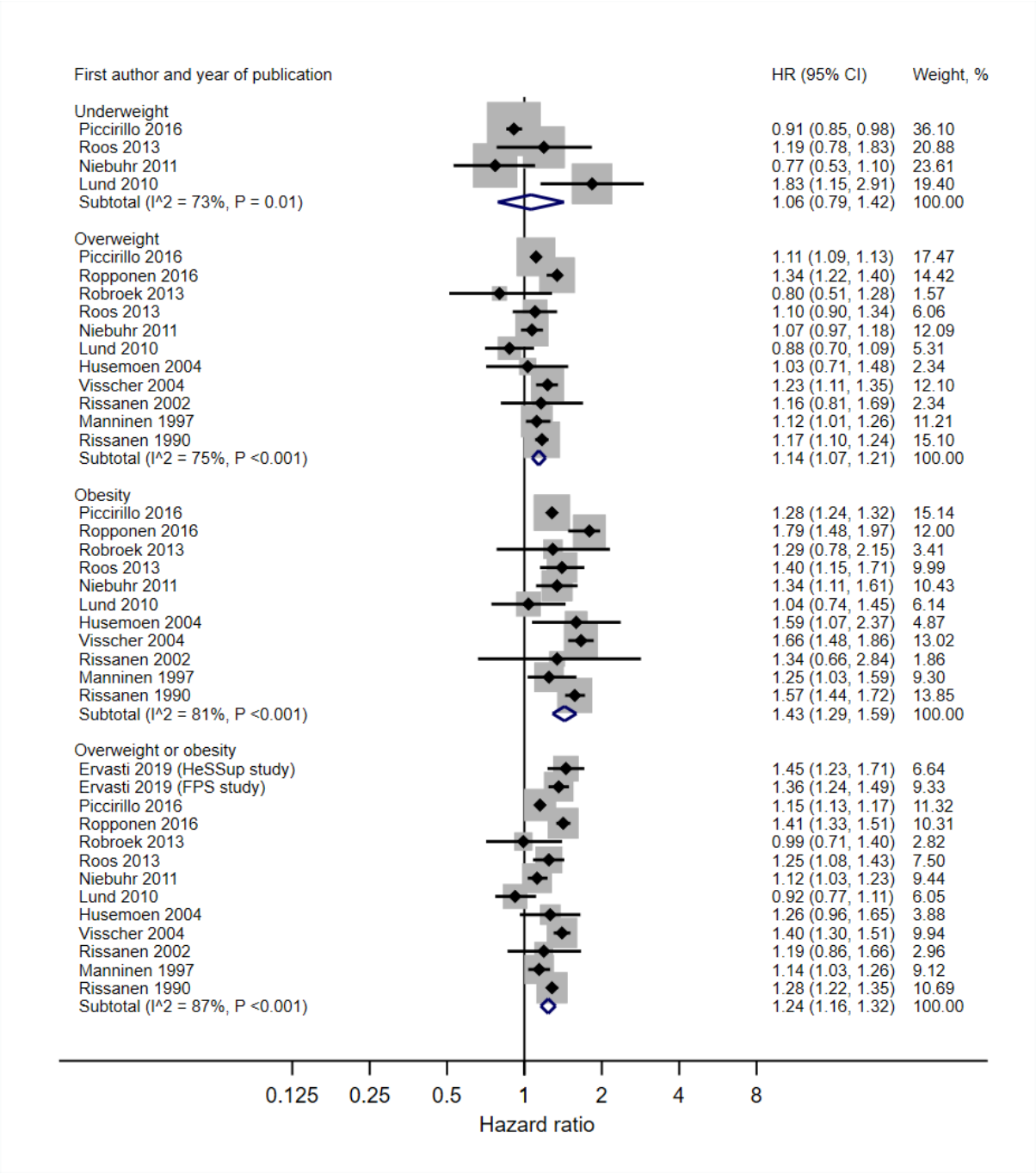
Supplementary Figure 3: Funnel plot of 17 studies on the association between obesity and all-cause disability retirement (P for Egger test=0.93)



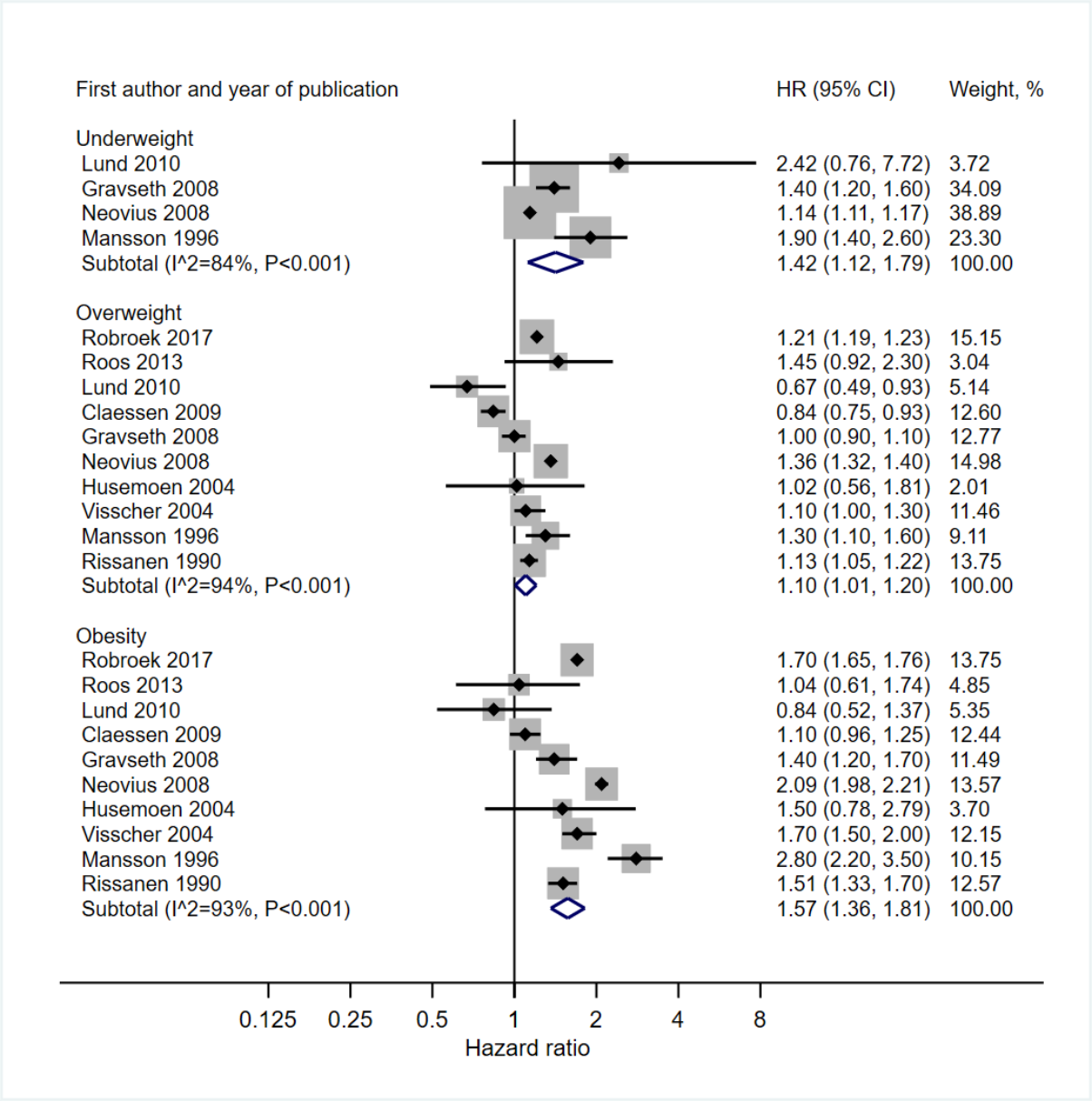
Supplementary Figure 4: A meta-analysis of seven prospective cohort studies with follow-up time up to 10 years on the association between body mass index and all-cause disability retirement



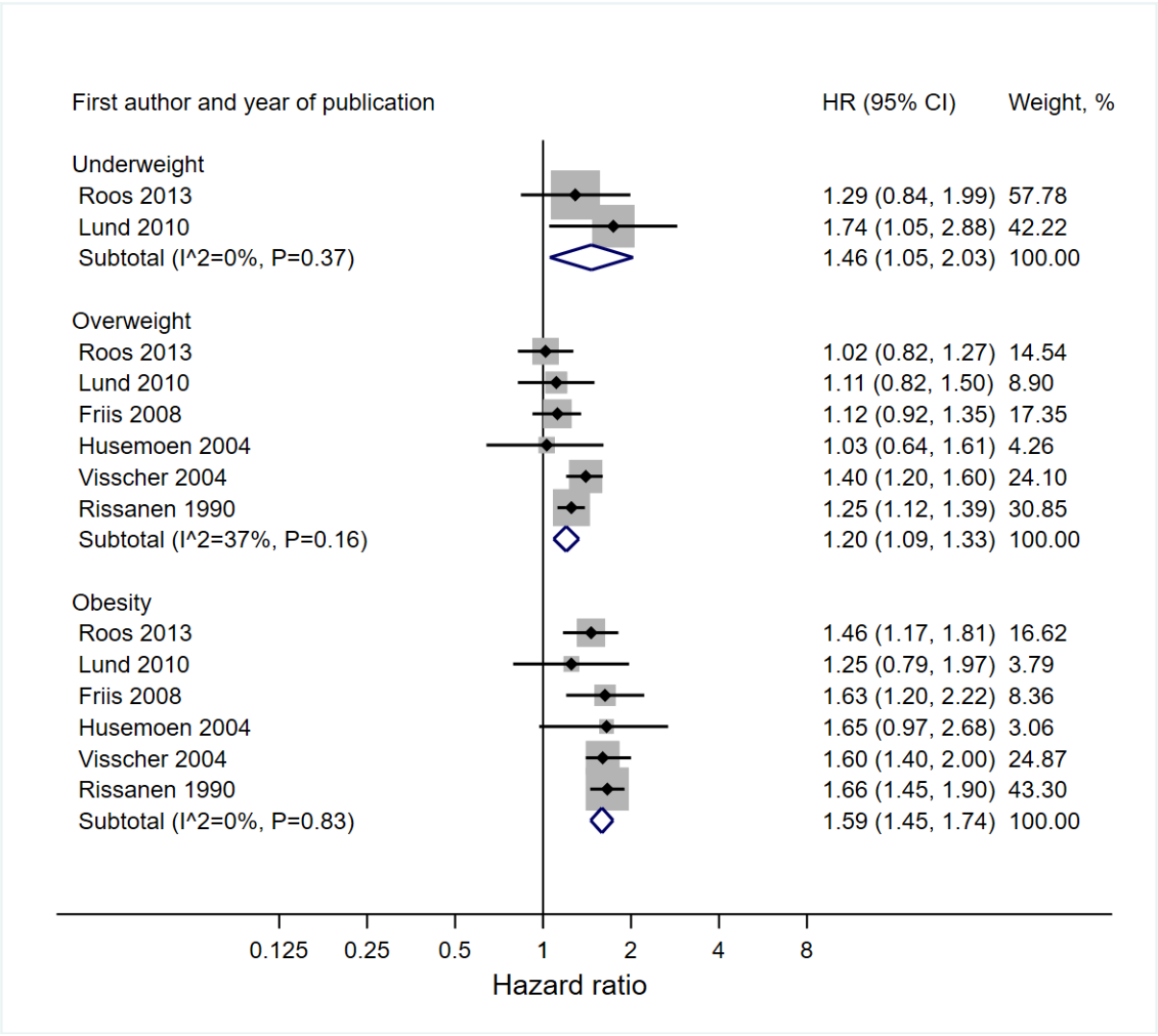
Supplementary Figure 5: A meta-analysis of 10 prospective cohort studies with follow-up time longer than 10 years on the association between body mass index and all-cause disability retirement



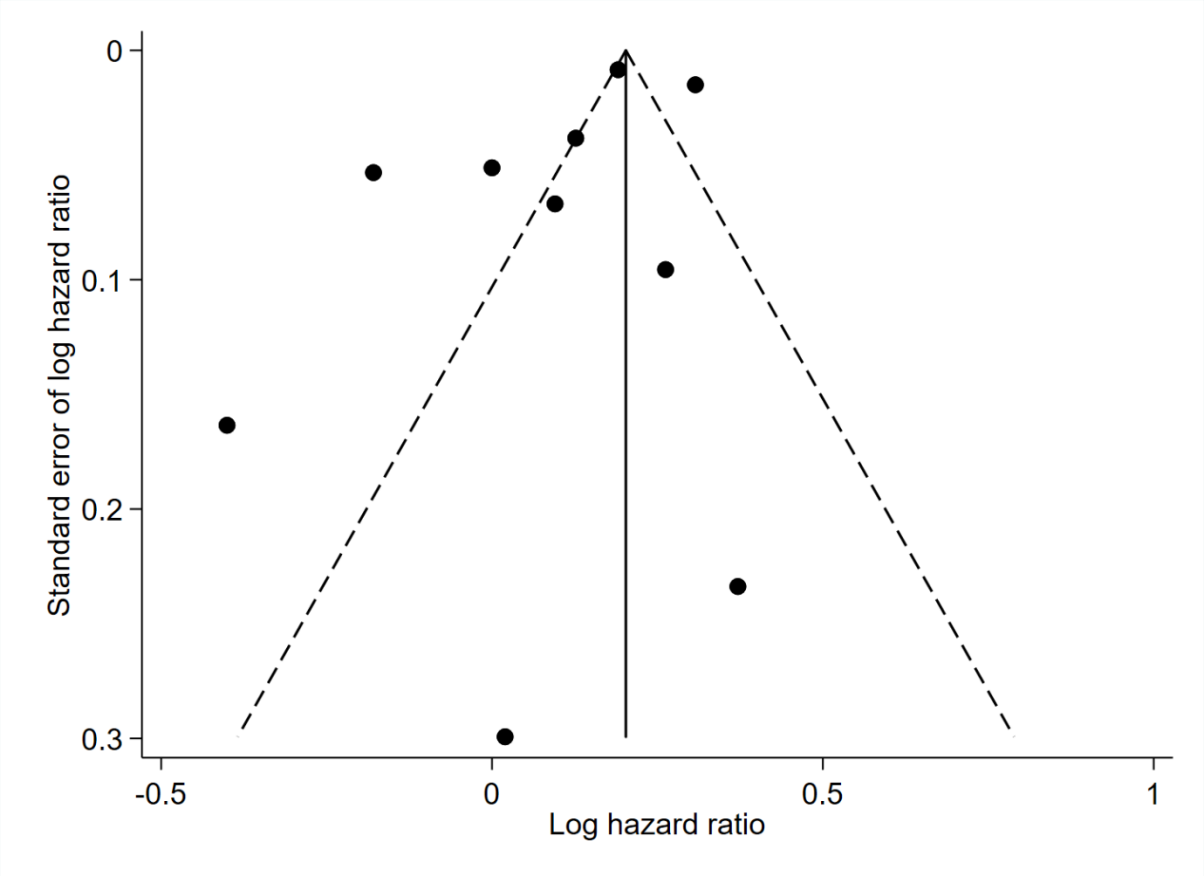
Supplementary Figure 6: A meta-analysis of 13 studies on the association between body mass index and all-cause disability retirement in both sexes



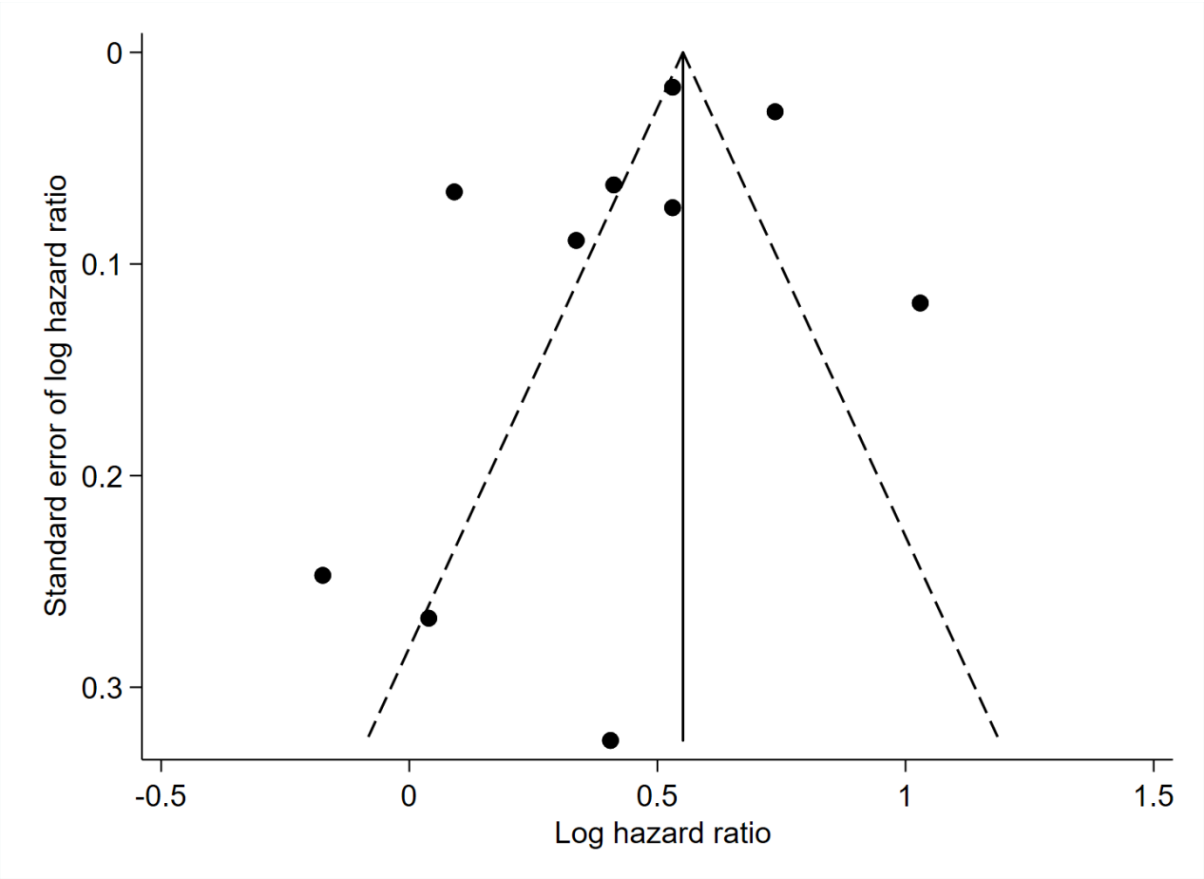
Supplementary Figure 7: A meta-analysis of 10 studies on the association between body mass index and all-cause disability retirement in men



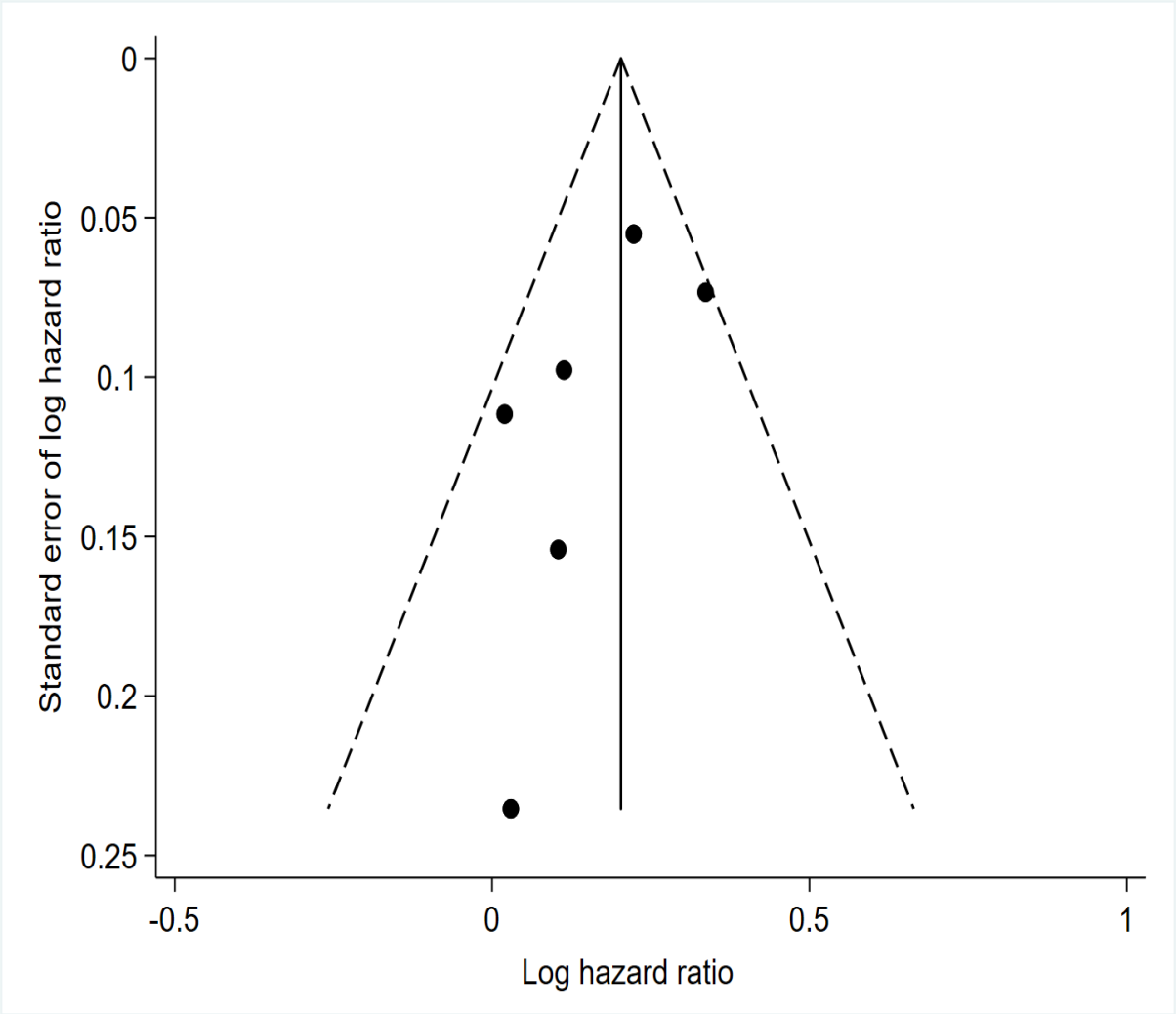
Supplementary Figure 8: A meta-analysis of six studies on the association between body mass index and all-cause disability retirement in women



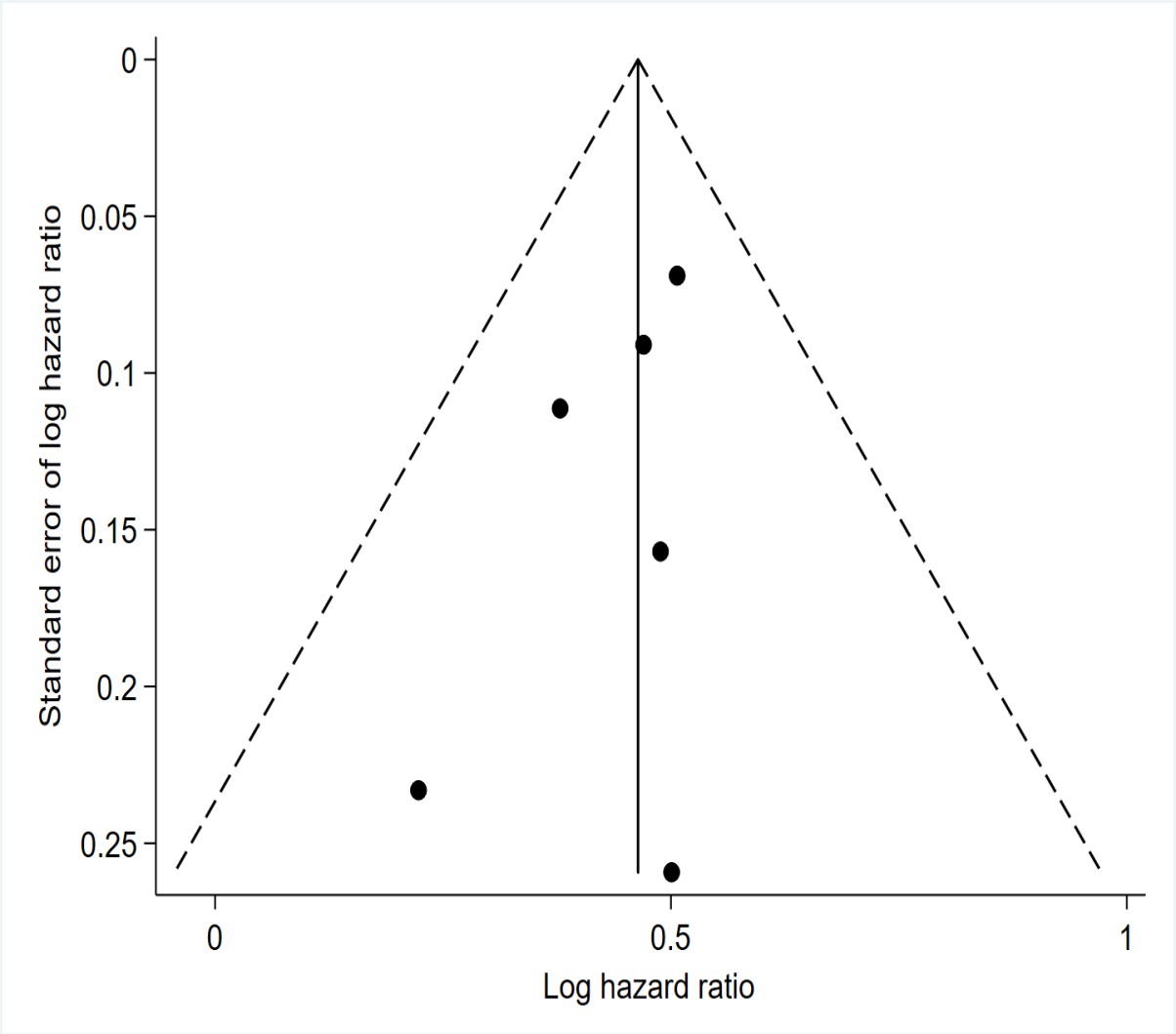
Supplementary Figure 9: Funnel plot of 10 studies on the association between obesity and all-cause disability retirement in men (P for Egger test=0.22)



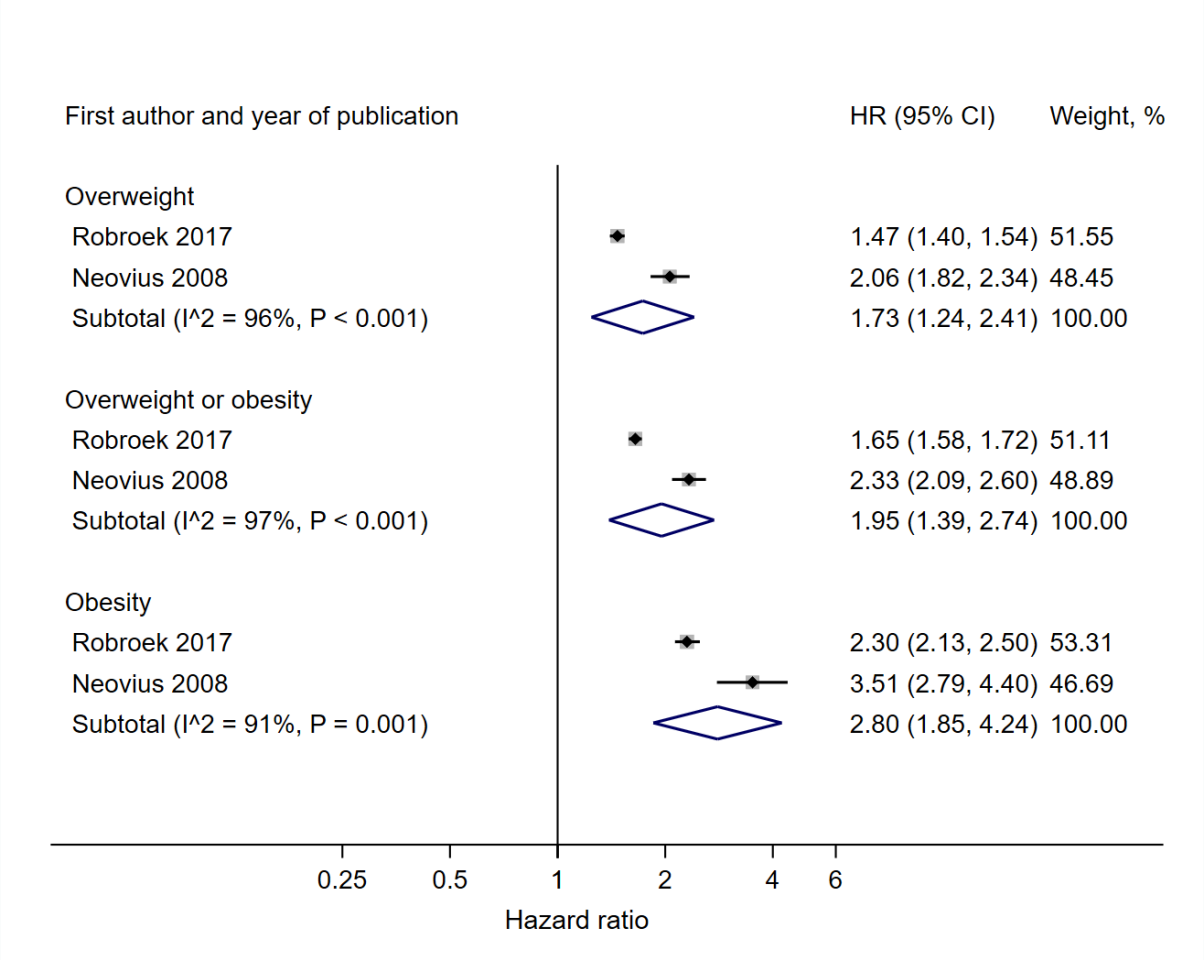
Supplementary Figure 10: Funnel plot of 10 studies on the association between obesity and all-cause disability retirement in men (P for Egger test=0.39)



Supplementary Figure 11: Funnel plot of six studies on the association between overweight and all-cause disability retirement in women (P for Egger test=0.18)



Supplementary Figure 12: Funnel plot of six studies on the association between obesity and all-cause disability retirement in women (P for Egger test=0.26)



Supplementary Figure 13: A meta-analysis of two studies on the association between body mass index and disability retirement due to cardiovascular diseases

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