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Bidirectional associations between adiposity and mental health: a prospective cohort study of the UK Biobank

Meng Lv[1] | Ying Li[2] | Zihan Guo[1] | Lu Ma[1,3] | Lei Zhang[4,5,6]

[1]China-Australia Joint Research Center for Infectious Diseases, School of Public Health, Xi'an Jiaotong University Health Science Center, Xi'an, Shaanxi, China

[2]Department of Respiratory and Critical Care Medicine, The Second Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi, China

[3]Key Laboratory for Disease Prevention and Control and Health Promotion of Shaanxi Province, Xi'an Jiaotong University Health Science Center, Xi'an, Shaanxi, China

[4]Phase I Clinical Trial Research Ward, The Second Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi, China

[5]Artificial Intelligence and Modelling in Epidemiology Program, Melbourne Sexual Health Centre, Alfred Health, Melbourne, Australia

[6]School of Translational Medicine, Faculty of Medicine, Nursing and Health Sciences, Monash University, Melbourne, Australia

Correspondence
Lu Ma and Lei Zhang
Email: maluhappy14@163.com and lei.zhang1@monash.edu

Abstract

Objective: This study aimed to examine the bidirectional associations between indicators of adiposity and mental health.

Methods: Using longitudinal data from 60,319 UK Biobank participants, we explored the bidirectional associations between mental health (including neuroticism, recent depressive symptoms, probable depression status, stress, mania, life satisfaction, and happiness) and adiposity indicators (including BMI, waist circumference, body fat percentage, and different obesity types).

Results: The multivariate logistic regressions and mixed-effects models revealed the following: 1) BMI and general obesity were bidirectionally associated with recent depressive symptoms, having probable depression status, experiencing at least one type of stress (especially stress from serious illness, injury, or assault to oneself or financial difficulties), and life satisfaction (especially health satisfaction and financial situation satisfaction); 2) waist circumference and abdominal obesity were bidirectionally associated with recent depressive symptoms and financial situation satisfaction; and 3) body fat percentage and high body fat percentage were bidirectionally associated with recent depressive symptoms, experiencing stress from financial difficulties, health satisfaction, and financial situation satisfaction.

Conclusions: The bidirectional associations between specific indicators of adiposity and mental health depend on the types of adiposity.

INTRODUCTION

Obesity has become a pressing global public health challenge. The age-standardized prevalence of obesity increased from 6.6% in 1990 to 15.8% in 2022 worldwide [1]. Concurrently, mental disorders persist as one of the top 10 leading causes of global disability-adjusted life years. The global burden of disability-adjusted life years attributable to mental disorders increased from 89.6 to 155.4 million between 1990 and 2021 [2]. When obesity and mental disorders coexist, they exacerbate disability, morbidity, and mortality, compounding adverse health outcomes. The COVID-19 pandemic induced unprecedented changes in lifestyle behaviors, further contributing to the prevalence of obesity and mental disorders [3]. In response, the World Health Organization (WHO) has enacted the "Accelerated Plan to Stop Obesity and Comprehensive Mental Health Action Plan 2013–2030" to curtail the prevalence of obesity and mental disorders [4, 5].

Mounting evidence has indicated bidirectional associations between obesity and mental disorders, with their co-occurrence being two times higher than expected [6]. Previous studies have shown that individuals with mental disorders have a two- to threefold increased

risk of developing obesity, and the risk of developing mental disorders for those who have obesity ranges from 30% to 70% [7]. Mental disorders such as major depression and bipolar disorder exhibit symptom profiles that can impact appetite and energy intake [8], thereby contributing to an increased risk of obesity. Conversely, obesity has been associated with stigmatization and cognitive and behavioral syndromes [9], heightening the risk of mental disorders. However, population-based epidemiological evidence remains inconsistent. For example, the studies by Colomer et al. and Christensen et al. suggested a bidirectional relationship between obesity and major depression, bipolar disorder, and mental stress [10, 11]. However, the longitudinal study by Fezeu et al. showed that the direction of association between mental disorders and adiposity is from common mental disorders (the 30-item General Health Questionnaire >4) to the increased risk of developing obesity, as opposed to the converse [12].

Despite increasing evidence, there are still significant gaps in understanding this complex relationship. First, although most of the existing studies on this topic have predominantly focused on depression, obesity may intrinsically contribute to a spectrum of increased negative mental disorders, such as neuroticism and mania [13], as well as diminished positive mental health outcomes, such as life satisfaction and happiness. Unfortunately, studies exploring these aspects have been scarce. Second, although the limitations of body mass index (BMI) lie in its inability to reflect regional body fat distribution and distinguish between lean and fat mass, most of the previous studies assessing the associations between adiposity and mental disorders have been restricted to BMI as an index of general obesity [14]. Studies focusing on other measures such as abdominal obesity and high body fat percentage remain scarce.

To address these gaps, using the largest prospective population-scale cohort of the UK Biobank, we investigated the bidirectional associations of indicators of general obesity, abdominal obesity, and high body fat percentage with mental health indicators. The mental health indicators included positive indicators of happiness and life satisfaction, as well as negative indicators of neuroticism, depressive symptoms and probable depression, stress, and mania. These findings would shed insights into the intricate interplay between indicators of adiposity and mental health.

Study Importance

What is already known?

- Adiposity and mental disorders show bidirectional associations, but population-based evidence is inconsistent.
- Most studies have focused on depression and BMI, overlooking other mental health indicators and adiposity measures.

What does this study add?

- This study provides robust evidence of bidirectional associations between multiple adiposity indicators (BMI, waist circumference, body fat percentage, and different obesity types) and mental health indicators, including recent depressive symptoms, stress, and life satisfaction.

How might these results change the direction of research or the focus of clinical practice?

- Our findings highlight the need for an integrated approach in health care that considers both mental health and obesity management, rather than treating them in isolation.

METHODS

Study participants and design

The UK Biobank is a large-scale, population-based prospective study that recruited over 500,000 participants aged between 38 and 73 years across the UK at baseline (2006–2010) and followed them over time, with follow-up assessments conducted in 2012 to 2013, 2014 onward, and 2019 onward. A detailed description of enrollment procedures, data collection, and follow-up has been previously published [15]. Participants were included if they had complete data for all covariates and at least one of the mental health indicators and adiposity indicators. Those with missing follow-up data for all mental health or adiposity indicators were excluded from the analysis. Additionally, in multivariable logistic regression analyses, participants who had obesity at baseline were excluded when examining the effects of mental health indicators on the onset of obesity. Conversely, when examining the effects of adiposity indicators on the onset of mental health indicators, participants with preexisting mental health disorders at baseline were excluded. The details of the sample selection are provided in Figure S1.

Ethical considerations

Ethical approval of the UK Biobank study was granted by the North West Multi-centre Research Ethics Committee, the National Information Governance Board for Health and Social Care, and the Community Health Index Advisory Group [16]. This study was conducted under approval from the material transfer agreement with reference number 79244. All participants gave informed consent to participate.

Assessment of indicators of general obesity, abdominal obesity, and high body fat percentage

Body weight, height, waist circumference, and body fat percentage were measured at baseline and follow-up using the same standardized protocols [17]. Body weight and body fat percentage were measured

using a Tanita BC-418 body composition analyzer (Tanita Corp.). Height was measured with a Seca 202 height measure (Seca GmbH). Waist circumference was measured using a Seca 200 tape measure. BMI was calculated as weight (kilograms) divided by height (meters squared). General obesity was defined as BMI ≥ 30 kg/m^2 [18]. Abdominal obesity was defined as waist circumference ≥ 102 cm for men or ≥88 cm for women [19]. High body fat percentage was defined as body fat percentage ≥ 25% for men or ≥35% for women [20]. BMI, waist circumference, and body fat percentage were treated as continuous variables, whereas general obesity, abdominal obesity, and high body fat percentage were used as binary variables in the data analyses.

Assessment of mental health indicators

Self-completed touch screen questionnaires facilitated the collection of mental health indicator data, encompassing seven distinct mental health indicators. (1) Neuroticism score, measured by the 12-item Eysenck Personality Questionnaire (range: 0–12, Cronbach $\alpha = 0.83$) [21]. High neuroticism was defined as a total score ≥6. (2) Recent depressive symptoms, measured by the four-item Recent Depressive Symptoms questionnaire (range: 4–16, Cronbach $\alpha = 0.79$), which is a continuous measure of depressive symptoms over the past 2 weeks [22]. (3) Probable depression status, defined as a positive to having ever felt depressed/unenthusiastic or disinterested, along with at least 1 week of depression/unenthusiasm or disinterest and a history of having seen either a doctor or psychiatrist for nerves, anxiety, tension, or depression [22]. (4) Stress, measured by items measuring specific major stressful life events in the last 2 years [23]. The events encompassed "serious illness, injury, or assault to the participants"; "serious illness, injury, or assault of a close relative"; "death of a close relative"; "death of a spouse or partner"; "marital separation/divorce"; and "financial difficulties." Participants reporting any of these events were classified as experiencing stress. (5) Mania, identified through two questions probing elevated mood or irritability lasting at least 2 days, alongside a checklist of manic symptoms. Participants were considered as having probable mania if they endorsed irritability or hyperactivity for at least 2 days and experienced three or more manic symptoms [24]. (6) Life satisfaction, evaluated based on the following five domains: work/job satisfaction, health satisfaction, family relationship satisfaction, friendship satisfaction, and financial situation satisfaction (Cronbach $\alpha = 0.67$) [25]. Each domain was scored from 1 (extremely happy) to 6 (extremely unhappy), with the total score ranging from 6 to 30. (7) Happiness, measured using the item "In general, how happy are you?" with responses recorded on a six-point Likert scale in reverse order. This single-item measure has been widely used in happiness research and has demonstrated good reliability and validity [26]. The specific UK Biobank identifiers and measures for each mental health indicator are shown in Table S1. Neuroticism score, recent depressive symptoms, life satisfaction, and happiness were treated as continuous variables, whereas high neuroticism, probable depression status, stress, and mania were treated as binary variables in our data analyses.

Assessment of covariates

Covariates included age (in years), sex (male and female), ethnicity (White and other ethnic groups), professional qualifications (college or university degree; Advanced levels/Advanced Subsidiary [AS] levels or equivalent; Ordinary [O] levels/General Certificate of Secondary Education [GCSE] degrees or equivalent; Cambridge School Examination [CSE] degrees or equivalent; National Vocational Qualification [NVQ], Higher National Diploma [HND], Higher National Certificate [HNC], or equivalent; and other professional qualifications), current employment status (in paid employment or self-employed, retired, and unemployed), smoking status (ever smoker and never smoker), alcohol intake (never, previous, and current), unhealthy dietary intake (fruit, vegetable, whole grain, fish, milk, vegetable oil, refined grain, processed meat, unprocessed meat, and sugary drink) [27], physical inactivity (sedentary behaviors and lack of physical activity), and major diseases (presence of cardiovascular disease, diabetes, cancer, and other serious medical conditions, scored as yes or no). These variables were self-reported via a touch screen questionnaire at baseline.

Statistical analysis

First, the sociodemographic characteristics of the participants were described. Mean (standard deviation [SD]) or median (interquartile range [IQR]) were presented for continuous data based on their normality, as determined by Kolmogorov–Smirnov tests. Categorical variables are described by the count of individuals and the proportion they represent within the total population. Second, multivariate logistic regressions and mixed-effects models were used to explore the longitudinal associations between mental health indicators and adiposity indicators and vice versa, adjusting for covariates. Multivariate logistic regressions were used for binary variables, whereas mixed-effects models were applied for continuous variables. Effect sizes were expressed as β and 95% confidence interval (CI) for continuous outcomes and as odds ratio (OR) and 95% CI for categorical outcomes. In each logistic regression model, associations between the exposure variable at baseline and the outcome variable at follow-up were assessed among participants without prior diseases at baseline, and we defined a positive result as any positive outcome recorded during any of the follow-up assessments. In the mixed-effects models, we included data from all surveys and analyzed the relationships between exposures at time t and outcomes at time $t + 1$. We used participant's identification as a random intercept to account for interindividual variation, and we incorporated follow-up time and covariates at time t as a fixed effect to adjust for the potential impact of temporal changes and confounding factors. In our study, each mental health or adiposity

indicator was analyzed in a separate model to assess its independent association with outcomes.

The analyses were performed using R version 4.2.1 (The R Foundation for Statistical Computing). A two-sided $p < 0.05$ was considered statistically significant.

RESULTS

Table 1 presents the baseline sociodemographic characteristics, adiposity indicators, and mental health indicators for the study cohort, comprising 60,319 individuals, 48.38% of whom were male. The participants were primarily recruited between 2008 and 2009 and had a median age of 57 years. More than 90% were White and ~65% were employed. At baseline, 19.07% of the participants were classified as having general obesity, 26.28% had abdominal obesity, and 50.82% had high body fat percentage. Additionally, 29.07% of the participants reported high neuroticism, 7.48% were identified as having probable depression status, 41.47% had experienced at least one type of stress, and 2.71% had mania disorder. Significant sex differences were observed in these indicators of adiposity and mental health.

Participants with recent depressive symptoms, stress, mania, or financial situation dissatisfaction consistently exhibit higher levels of adiposity indicators

Figure 1A illustrates the results of the longitudinal associations between mental health indicators and continuous adiposity outcomes. Recent depressive symptoms (β = 0.08, 0.06–0.09) and probable depression status (β = 0.11, 0.03–0.20) were associated with an elevated BMI. Participants experiencing stress (β = 0.09, 0.04–0.14), particularly stress from serious illness, injury, or assault to themselves (β = 0.21, 0.11–0.32), marital separation/divorce (β = 0.24, 0.04–0.45), or financial difficulties (β = 0.41, 0.27–0.55), were more likely to have a higher BMI. Similarly, participants expressing dissatisfaction with life (β = 0.06, 0.04–0.08), especially dissatisfaction with health (β = 0.59, 0.51–0.67), family relationships (β = 0.08, 0.01–0.15), or financial situation (β = 0.30, 0.23–0.37), were also more prone to a higher BMI, respectively. In general, the associations between mental health indicators and waist circumference and body fat percentage were similar to those of BMI. However, probable depression status and dissatisfaction with family relationships were not associated with waist circumference or body fat percentage. Additionally, neuroticism score and high neuroticism were associated with waist circumference but not BMI or body fat percentage.

Figure 1B illustrates the results of logistic regression analyses examining associations between mental health indicators and the risk of developing obesity. Neuroticism score (OR = 1.02, 1.01–1.04), high neuroticism (OR = 1.15, 1.05–1.26), recent depressive symptoms (OR = 1.08, 1.06–1.10), and probable depression status (OR = 1.29, 1.12–1.48) were associated with an increased risk of general obesity, respectively. Participants who experienced stress had higher odds of general obesity (OR = 1.22, 1.13–1.32), particularly those who experienced stress from serious illness, injury, or assault to themselves (OR = 1.47, 1.26–1.71), marital separation/divorce (OR = 1.37, 1.07–1.76), and financial difficulties (OR = 1.78, 1.52–2.09). Participants who had mania also had a higher likelihood of general obesity (OR = 1.82, 1.27–2.61). Additionally, participants who were not satisfied with their life (OR = 1.06, 1.03–1.08), especially those who were not satisfied with their health (OR = 1.38, 1.25–1.52), family relationships (OR = 1.10, 1.01–1.19), and financial situation (OR = 1.28, 1.18–1.39), were more likely to have general obesity. In contrast, probable depression status and dissatisfaction with health and family relationships were not associated with the risk of developing abdominal obesity. Neuroticism score, high neuroticism, probable depression status, mania, and dissatisfaction with family relationships were not associated with the risk of high body fat percentage. Aside from these findings, the remaining results were consistent with those observed for general obesity.

The findings by sex are shown in Figures S2 and S3. Overall, the results are consistent with those observed in the total population, with the following exceptions: stress from financial difficulties was not associated with all adiposity indicators except for general obesity and high body fat percentage in male individuals, and stress was not associated with the risk of high body fat percentage in female individuals.

Participants with higher adiposity indicators consistently exhibit higher risks of recent depressive symptoms, health dissatisfaction, and financial situation dissatisfaction

Figure 2A illustrates the results of the longitudinal associations between continuous adiposity indicators and mental health outcomes. A higher BMI was associated with a higher score of recent depressive symptoms (OR = 1.11, 1.07–1.15) and heightened odds of probable depression status (OR = 1.11, 1.09–1.14). BMI also exhibits positive associations with having at least one stressor (OR = 1.05, 1.02–1.07), especially stress from serious illness, injury, or assault to oneself (OR = 1.08, 1.03–1.12) and financial difficulties (OR = 1.24, 1.17–1.32). Participants with a higher BMI was also more likely to be less satisfied with their life (OR = 1.19, 1.10–1.29), particularly their health (OR = 1.15, 1.13–1.17) or financial situation (OR = 1.06, 1.04–1.08). In general, waist circumference and body fat percentage exhibited similar associations with these mental health outcomes compared with BMI. However, waist circumference was not associated with having at least one stressor and stress from serious illness, injury, or assault to oneself or financial difficulties, but it was associated with almost all aspects of life satisfaction.

Figure 2B presents the results of the associations between categorical adiposity indicators and mental health outcomes. Participants with general obesity were more likely to report more recent depressive symptoms (OR = 1.24, 1.18–1.31) and to have a probable depression status (OR = 1.22, 1.16–1.29). They were also more likely to experience stress (OR = 1.09, 1.03–1.16), particularly stress from

TABLE 1 Baseline demographic characteristics of the study participants.

	All ($N = 60,319$)	Male ($n = 29,181$)	Female ($n = 31,138$)	p value
Year of study entry, *n* (%)				0.472
2006–2007	8547 (14.17)	4094 (14.03)	4453 (14.30)	
2008–2009	41,651 (69.05)	20,148 (69.04)	21,503 (69.06)	
2010	10,121 (16.78)	4939 (16.93)	5182 (16.64)	
Age, median (IQR), y	57.00 (50.00, 62.00)	58.00 (51.00, 62.00)	56.00 (49.00, 61.00)	<0.001
Ethnicity, *n* (%)				<0.001
White	55,806 (92.54)	27,138 (93.02)	28,668 (92.10)	
Other ethnic groups	4344 (7.20)	1949 (6.68)	2395 (7.69)	
Don't know/prefer not to answer	152 (0.25)	87 (0.30)	65 (0.21)	
Professional qualifications, *n* (%)				<0.001
College or university degree	26,635 (44.84)	13,277 (46.18)	13,358 (43.57)	
A levels/AS levels or equivalent	7549 (12.71)	3301 (11.48)	4248 (13.86)	
O levels/GCSE or equivalent	11,659 (19.63)	5043 (17.54)	6616 (21.58)	
CSE or equivalent	2408 (4.05)	1162 (4.04)	1246 (4.06)	
NVQ, HND, HNC, or equivalent	3456 (5.82)	2404 (8.36)	1052 (3.43)	
Other professional qualifications	2999 (5.05)	1187 (4.13)	1812 (5.91)	
None of the above/prefer not to answer	4700 (7.91)	2374 (8.26)	2326 (7.59)	
Current employment status, *n* (%)				<0.001
In paid employment or self-employed	39,221 (65.04)	19,414 (66.55)	19,807 (63.63)	
Retired	17,307 (28.70)	8455 (28.98)	8852 (28.44)	
Unemployed	3391 (5.62)	1116 (3.83)	2275 (7.31)	
None of the above/prefer not to answer	383 (0.64)	189 (0.65)	194 (0.62)	
Neighborhood deprivation index, median (IQR)				
England	11.83 (7.15, 20.80)	11.76 (7.10, 20.74)	11.91 (7.20, 20.83)	0.121
Scotland	5.56 (3.10, 11.11)	5.45 (3.07, 10.85)	5.65 (3.18, 11.85)	0.222
Wales	13.60 (8.90, 21.70)	13.60 (8.90, 19.00)	14.10 (8.90, 22.38)	0.445
BMI, median (IQR), kg/m^2	26.14 (23.73, 29.00)	26.81 (24.62, 29.28)	25.32 (22.98, 28.61)	<0.001
<18.5 (underweight)	260 (0.43)	35 (0.12)	225 (0.72)	
18.5–24.9 (healthy weight)	22,688 (37.68)	8395 (28.83)	14,293 (45.98)	
25.0–29.9 (overweight)	25,777 (42.81)	14,838 (50.95)	10,939 (35.19%)	
≥30.0 (general obesity)	11,482 (19.07)	5853 (20.10)	5629 (18.11)	
Waist circumference, median (IQR), cm	88.00 (79.00, 97.00)	94.00 (88.00, 101.00)	81.00 (74.00, 89.00)	<0.001
Abdominal obesity, *n* (%)[a]	15,833 (26.28)	6976 (23.93)	8857 (28.47)	<0.001
Body fat percentage, median (IQR), %	29.70 (24.20, 36.20)	24.60 (21.00, 28.10)	35.70 (31.00, 40.20)	<0.001
High body fat percentage, *n* (%)[b]	30,219 (50.82)	13,638 (47.42)	16,581 (54.02)	<0.001
Neuroticism score, median (IQR)	3.00 (1.00, 6.00)	3.00 (1.00, 5.00)	4.00 (2.00, 6.00)	<0.001
High neuroticism, *n* (%), yes	17,336 (29.07)	6961 (24.12)	10,375 (33.71)	<0.001
Recent depressive symptoms score, median (IQR)	5.00 (4.00, 6.00)	5.00 (4.00, 6.00)	5.00 (4.00, 6.00)	<0.001
Probable depression status, *n* (%), yes	4509 (7.48)	1728 (5.93)	2781 (8.94)	<0.001
Stress (at least 1 type), *n* (%), yes	24,634 (41.47)	11,407 (39.68)	13,227 (43.14)	<0.001
Type of stress, *n* (%), yes				<0.001
Serious illness, injury, or assault to yourself	4154 (6.99)	2212 (7.69)	1942 (6.33)	
Serious illness, injury, or assault of close relative	6973 (11.74)	2597 (9.03)	4376 (14.27)	
Death of a close relative	8959 (15.08)	4380 (15.24)	4579 (14.94)	
Death of a spouse or partner	461 (0.78)	165 (0.57)	296 (0.97)	
Marital separation/divorce	1167 (1.96)	546 (1.90)	621 (2.03)	

(Continues)

TABLE 1 (Continued)

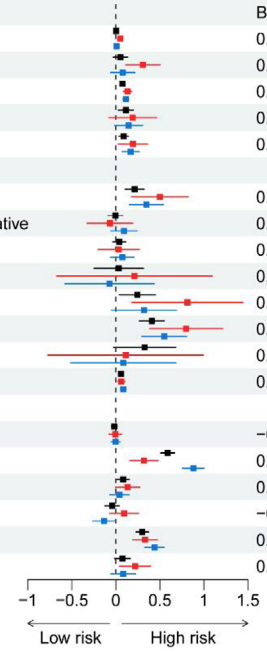
	All (N = 60,319)	Male (n = 29,181)	Female (n = 31,138)	p value
Financial difficulties	2920 (4.92)	1507 (5.24)	1413 (4.61)	
None of the above/prefer not to answer	34,772 (58.53)	17,341 (60.32)	17,431 (56.86)	
Mania, *n* (%), yes	512 (2.71)	278 (3.01)	234 (2.42)	0.015
Life satisfaction score, median (IQR)	13.00 (11.00, 15.00)	13.00 (11.00, 16.00)	13.00 (11.00, 15.00)	<0.001
Work/job satisfaction	3.00 (2.00, 6.00)	3.00 (2.00, 6.00)	3.00 (2.00, 7.00)	0.192
Health satisfaction	3.00 (2.00, 3.00)	3.00 (2.00, 3.00)	3.00 (2.00, 3.00)	0.008
Family relationship satisfaction	2.00 (2.00, 3.00)	2.00 (2.00, 3.00)	2.00 (2.00, 3.00)	0.055
Friendship satisfaction	2.00 (2.00, 3.00)	2.00 (2.00, 3.00)	2.00 (2.00, 3.00)	<0.001
Financial situation satisfaction	3.00 (2.00, 3.00)	3.00 (2.00, 3.00)	3.00 (2.00, 3.00)	0.055
Happiness score, median (IQR)	3.00 (2.00, 3.00)	3.00 (2.00, 3.00)	3.00 (2.00, 3.00)	0.002
Smoking status, *n* (%)				<0.001
Ever/current smoker	34,613 (57.52)	18,012 (61.89)	16,601 (53.43)	
Never smoker	25,562 (42.48)	11,093 (38.11)	14,469 (46.57)	
Alcohol intake, *n* (%)				<0.001
Never	1623 (2.69)	534 (1.83)	1089 (3.50)	
Previous	1393 (2.31)	653 (2.24)	740 (2.38)	
Current	57,266 (94.97)	27,979 (95.90)	29,287 (94.09)	
Prefer not to answer	20 (0.03)	8 (0.03)	12 (0.04)	
Unhealthy dietary intake, *n* (%)[c]				
Fruit	28,321 (47.23)	15,696 (54.11)	12,625 (40.79)	<0.001
Vegetable	10,192 (16.95)	6041 (20.80)	4151 (13.35)	<0.001
Whole grain	49,978 (83.80)	23,001 (79.43)	26,977 (87.93)	<0.001
Fish	14,836 (24.62)	7236 (24.82)	7600 (24.43)	0.264
Milk	57,117 (96.39)	27,638 (96.26)	29,479 (96.50)	0.121
Vegetable oil	32,406 (54.55)	13,613 (47.35)	18,793 (61.30)	<0.001
Refined grain	9136 (15.32)	6481 (22.38)	2655 (8.65)	<0.001
Processed meat	18,144 (30.11)	12,126 (41.59)	6018 (19.35)	<0.001
Unprocessed meat	55,941 (92.79)	27,684 (94.92)	28,257 (90.79)	<0.001
Sugary drink	50,436 (85.00)	23,959 (83.42)	26,477 (86.48)	<0.001
Physical inactivity, *n* (%)[d]				
Sedentary behaviors	12,850 (21.38)	6359 (21.85)	6491 (20.94)	0.007
Lack of physical activity	3037 (6.44)	1509 (6.51)	1528 (6.38)	0.588

Note: Continuous variables are presented as median with IQR, as Kolmogorov–Smirnov tests indicated that these variables deviated from normality ($p < 0.05$). Categorical variables are described by the count of individuals and the proportion they represent within the total population.
Abbreviations: A levels, Advanced levels; AS levels, Advanced Subsidiary levels; CSE, Cambridge School Examination; GCSE, General Certificate of Secondary Education; HNC, Higher National Certificate; HND, Higher National Diploma; NVQ, National Vocational Qualification; O levels, Ordinary levels.
[a]Abdominal obesity was defined as waist circumference ≥ 102 cm in men and ≥88 cm in women.
[b]High body fat percentage was defined as body fat percentage ≥ 25% for men or ≥35% for women.
[c]Consuming <3 pieces of fruit per day was considered a risk; consuming <3 tablespoons of vegetables per day was considered a risk; consuming <3 servings of whole grain per day was considered a risk; consuming fish <2 times per week was considered a risk; consuming milk <1 time per day was considered a risk; consuming vegetable oil <2 times per week was considered a risk; consuming >2 bowls of refined grain per day was considered a risk; consuming processed meat >1 time per week was considered a risk; consuming unprocessed meat >1 time per week was considered a risk; and consuming a sugary drink was considered a risk.
[d]Watching television ≥4 h/day was considered as sedentary behavior; and duration of vigorous physical activity <75 min/week or duration of moderate physical activity <150 min/week was considered as lack of physical activity.

serious illness, injury, or assault to themselves (OR = 1.21, 1.09–1.35) and financial difficulties (OR = 1.49, 1.28–1.74). Participants who had general obesity were more likely to have mania (OR = 1.46, 1.04–2.05). Moreover, they were more likely to be dissatisfied with their life (OR = 1.44, 1.30–1.60), especially dissatisfied with their health (OR = 1.25, 1.22–1.28) and financial situation (OR = 1.14, 1.11–1.17). In contrast, abdominal obesity was not associated with the risk of probable depression status and mania or experiencing any type of

(A)

Mental health indicators (exposure)	Body mass index	Waist circumference	Body fat percentage
	Beta (95%CI)	Beta (95%CI)	Beta (95%CI)
Neuroticism score	0.00 (−0.01, 0.02)	0.05 (0.02, 0.08)***	0.01 (−0.01, 0.03)
High neuroticism	0.05 (−0.03, 0.13)	0.31 (0.11, 0.50)**	0.08 (−0.06, 0.22)
Recent depressive symptoms	0.08 (0.06, 0.09)***	0.13 (0.08, 0.18)***	0.11 (0.08, 0.15)***
Probable depression status	0.11 (0.03, 0.20)**	0.19 (−0.08, 0.46)	0.15 (−0.01, 0.30)
Stress (at least one)	0.09 (0.04, 0.14)**	0.19 (0.03, 0.36)*	0.17 (0.07, 0.27)***
Type of stress			
Serious illness,injury or assault to yourself	0.21 (0.11, 0.32)***	0.50 (0.18, 0.82)**	0.35 (0.15, 0.54)***
Serious illness,injury or assault of a close relative	0.00 (−0.09, 0.08)	−0.07 (−0.33, 0.19)	0.09 (−0.06, 0.24)
Death of a close relative	0.04 (−0.03, 0.11)	0.03 (−0.20, 0.27)	0.07 (−0.06, 0.21)
Death of a spouse or partner	0.03 (−0.25, 0.31)	0.21 (−0.67, 1.09)	−0.07 (−0.58, 0.43)
Marital separation/divorce	0.24 (0.04, 0.45)*	0.81 (0.18, 1.44)*	0.32 (−0.05, 0.69)
Financial difficulties	0.41 (0.27, 0.55)***	0.80 (0.38, 1.21)***	0.55 (0.30, 0.80)***
Mania	0.33 (−0.03, 0.68)	0.11 (−0.77, 0.99)	0.08 (−0.51, 0.68)
Life satisfaction	0.06 (0.04, 0.08)***	0.06 (0.02, 0.10)**	0.08 (0.05, 0.12)***
Type of life satisfaction			
Work/job satisfaction	−0.02 (−0.05, 0.01)	−0.01 (−0.08, 0.06)	0.00 (−0.05, 0.05)
Health satisfaction	0.59 (0.51, 0.67)***	0.32 (0.16, 0.48)***	0.88 (0.76, 1.00)***
Family relationship satisfaction	0.08 (0.01, 0.15)*	0.13 (0.00, 0.27)	0.04 (−0.07, 0.15)
Friendships satisfaction	−0.04 (−0.12, 0.04)	0.09 (−0.07, 0.26)	−0.13 (−0.26, −0.01)*
Financial situation satisfaction	0.30 (0.23, 0.37)***	0.33 (0.19, 0.47)***	0.44 (0.33, 0.55)***
Happiness	0.08 (−0.01, 0.16)	0.22 (0.04, 0.39)*	0.08 (−0.06, 0.22)



(B)

Mental health indicators (exposure)	General obesity	Abdominal obesity	High body fat percentage
	OR (95%CI)	OR (95%CI)	OR (95%CI)
Neuroticism score	1.02 (1.01, 1.04)***	1.02 (1.01, 1.03)***	1.01 (1.00, 1.02)
High neuroticism	1.15 (1.05, 1.26)**	1.09 (1.02, 1.16)*	1.01 (0.95, 1.07)
Recent depressive symptoms	1.08 (1.06, 1.10)***	1.06 (1.04, 1.08)***	1.05 (1.03, 1.06)***
Probable depression status	1.29 (1.12, 1.48)***	1.02 (0.91, 1.14)	1.02 (0.91, 1.14)
Stress (at least one)	1.22 (1.13, 1.32)***	1.09 (1.03, 1.16)**	1.06 (1.00, 1.12)
Type of stress			
Serious illness,injury or assault to yourself	1.47 (1.26, 1.71)***	1.21 (1.06, 1.37)**	1.16 (1.04, 1.31)*
Serious illness,injury or assault of a close relative	1.08 (0.95, 1.23)	1.01 (0.92, 1.11)	0.97 (0.89, 1.06)
Death of a close relative	1.03 (0.91, 1.16)	1.01 (0.93, 1.11)	1.01 (0.93, 1.09)
Death of a spouse or partner	1.45 (0.94, 2.22)	1.29 (0.94, 1.77)	1.22 (0.90, 1.64)
Marital separation/divorce	1.37 (1.07, 1.76)*	1.45 (1.19, 1.77)***	1.26 (1.06, 1.50)*
Financial difficulties	1.78 (1.52, 2.09)***	1.26 (1.09, 1.45)**	1.25 (1.10, 1.42)***
Mania	1.82 (1.27, 2.61)**	1.67 (1.21, 2.31)**	1.37 (1.00, 1.88)
Life satisfaction	1.06 (1.03, 1.08)***	1.02 (1.00, 1.04)	1.02 (1.00, 1.04)
Type of life satisfaction			
Work/job satisfaction	0.99 (0.94, 1.04)	0.99 (0.95, 1.02)	0.99 (0.95, 1.02)
Health satisfaction	1.38 (1.25, 1.52)***	1.06 (0.98, 1.15)	1.13 (1.06, 1.22)***
Family relationship satisfaction	1.10 (1.01, 1.19)*	1.07 (1.00, 1.14)	1.02 (0.96, 1.08)
Friendships satisfaction	0.98 (0.89, 1.09)	1.01 (0.93, 1.09)	1.01 (0.94, 1.09)
Financial situation satisfaction	1.28 (1.18, 1.39)***	1.12 (1.05, 1.19)***	1.17 (1.10, 1.24)***
Happiness	1.11 (0.99, 1.23)	1.09 (1.00, 1.19)	1.04 (0.96, 1.12)

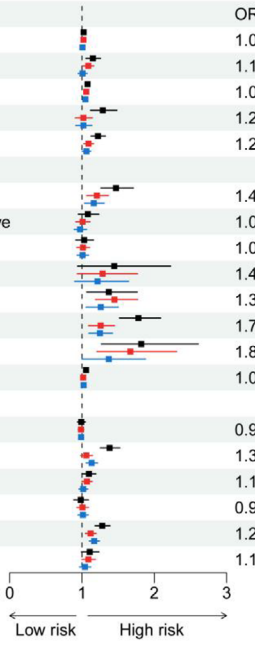
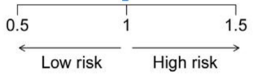
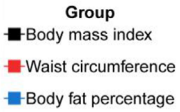


FIGURE 1 Observational analyses of the longitudinal associations between mental health indicators and adiposity outcomes. Multivariate logistic regressions were used for categorical outcome variables and mixed-effects models were used for continuous outcomes. Effect sizes were expressed as β and 95% CI for continuous outcomes and as OR and 95% CI for categorical outcomes. BMI, waist circumference, and body fat percentage were used as continuous variables, whereas general obesity, abdominal obesity, and high body fat percentage were used as categorical variables. Covariates included age, sex, ethnicity, professional qualifications, employment status, unhealthy dietary intake, physical inactivity, smoking, and alcohol intake. Models with waist circumference and abdominal obesity as the outcomes also adjusted for BMI. In the models, neuroticism score, recent depressive symptoms, life satisfaction, and happiness were used as continuous variables and other mental health indicators were used as categorical variables. Life satisfaction and happiness scores were reverse scored, with higher scores indicating lower satisfaction with life or happiness. *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$. OR, odds ratio. [Color figure can be viewed at wileyonlinelibrary.com]

(A)

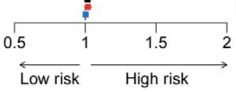
Mental health indicators (outcome)	Body mass index	Waist circumference	Body fat percentage
	OR (95%CI)	OR (95%CI)	OR (95%CI)
Neuroticism score	0.91 (0.84, 0.97)**	1.09 (1.01, 1.17)*	0.95 (0.89, 1.01)
High neuroticism	0.99 (0.95, 1.02)	1.04 (0.97, 1.13)	0.99 (0.93, 1.05)
Recent depressive symptoms	1.11 (1.07, 1.15)***	1.11 (1.06, 1.16)***	1.15 (1.11, 1.19)***
Probable depression status	1.11 (1.09, 1.14)***	1.08 (1.03, 1.14)**	1.19 (1.15, 1.24)***
Stress (at least one)	1.05 (1.02, 1.07)***	0.97 (0.92, 1.02)	1.08 (1.04, 1.12)***
Type of stress			
Serious illness,injury or assault to yourself	1.08 (1.03, 1.12)**	1.09 (0.99, 1.20)	1.10 (1.02, 1.19)*
Serious illness,injury or assault of a close relative	1.01 (0.98, 1.05)	0.99 (0.92, 1.07)	1.04 (0.98, 1.10)
Death of a close relative	1.03 (1.00, 1.06)	0.93 (0.87, 0.98)*	1.05 (1.01, 1.10)*
Death of a spouse or partner	1.05 (0.96, 1.16)	0.97 (0.80, 1.19)	1.13 (0.96, 1.32)
Marital separation/divorce	0.92 (0.84, 1.02)	1.20 (0.98, 1.49)	0.88 (0.75, 1.03)
Financial difficulties	1.24 (1.17, 1.32)***	1.12 (0.97, 1.29)	1.42 (1.27, 1.58)***
Mania	1.11 (0.96, 1.28)	0.89 (0.64, 1.24)	1.18 (0.91, 1.53)
Life satisfaction	1.19 (1.10, 1.29)***	1.28 (1.18, 1.40)***	1.30 (1.22, 1.40)***
Type of life satisfaction			
Work/job satisfaction	0.96 (0.91, 1.01)	1.07 (1.01, 1.14)*	1.02 (0.98, 1.07)
Health satisfaction	1.15 (1.13, 1.17)***	1.08 (1.06, 1.11)***	1.19 (1.17, 1.21)***
Family relationship satisfaction	1.02 (1.00, 1.04)	1.03 (1.00, 1.05)	1.01 (0.99, 1.02)
Friendships satisfaction	1.00 (0.98, 1.02)	1.03 (1.01, 1.05)***	0.99 (0.97, 1.00)
Financial situation satisfaction	1.06 (1.04, 1.08)***	1.04 (1.01, 1.06)**	1.09 (1.07, 1.11)***
Happiness	1.00 (0.98, 1.02)	1.03 (1.01, 1.05)**	0.99 (0.98, 1.01)





(B)

Mental health indicators (outcome)	General obesity	Abdominal obesity	High body fat percentage
	OR (95%CI)	OR (95%CI)	OR (95%CI)
Neuroticism score	1.02 (0.93, 1.11)	1.09 (1.00, 1.19)	0.98 (0.91, 1.05)
High neuroticism	1.00 (0.92, 1.09)	1.05 (0.95, 1.17)	1.01 (0.94, 1.08)
Recent depressive symptoms	1.24 (1.18, 1.31)***	1.07 (1.01, 1.13)*	1.13 (1.09, 1.18)***
Probable depression status	1.22 (1.16, 1.29)***	1.05 (0.98, 1.12)	1.17 (1.12, 1.23)***
Stress (at least one)	1.09 (1.03, 1.16)**	0.97 (0.90, 1.04)	1.05 (1.00, 1.10)
Type of stress			
Serious illness,injury or assault to yourself	1.21 (1.09, 1.35)***	1.05 (0.92, 1.20)	1.09 (1.00, 1.19)
Serious illness,injury or assault of a close relative	1.02 (0.93, 1.12)	0.97 (0.87, 1.08)	0.97 (0.90, 1.04)
Death of a close relative	1.03 (0.96, 1.10)	0.94 (0.86, 1.02)	1.07 (1.01, 1.13)*
Death of a spouse or partner	1.16 (0.91, 1.46)	0.96 (0.73, 1.26)	1.09 (0.90, 1.32)
Marital separation/divorce	0.98 (0.77, 1.26)	1.20 (0.90, 1.61)	0.83 (0.68, 1.00)
Financial difficulties	1.49 (1.28, 1.74)***	1.12 (0.92, 1.36)	1.37 (1.20, 1.57)***
Mania	1.46 (1.04, 2.05)*	1.33 (0.87, 2.04)	1.11 (0.81, 1.51)
Life satisfaction	1.44 (1.30, 1.60)***	1.27 (1.13, 1.42)***	1.27 (1.17, 1.38)***
Type of life satisfaction			
Work/job satisfaction	0.95 (0.89, 1.02)	1.05 (0.97, 1.13)	1.01 (0.96, 1.07)
Health satisfaction	1.25 (1.22, 1.28)***	1.06 (1.04, 1.09)***	1.17 (1.14, 1.19)***
Family relationship satisfaction	1.06 (1.03, 1.09)***	1.04 (1.01, 1.07)**	1.01 (0.99, 1.03)
Friendships satisfaction	1.02 (0.99, 1.04)	1.03 (1.00, 1.06)	0.99 (0.97, 1.01)
Financial situation satisfaction	1.14 (1.11, 1.17)***	1.06 (1.03, 1.09)***	1.08 (1.06, 1.11)***
Happiness	1.02 (0.99, 1.04)	1.02 (0.99, 1.04)	1.00 (0.99, 1.02)



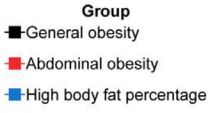


FIGURE 2 Observational analyses of the longitudinal associations between adiposity indicators and mental health outcomes. Multivariate logistic regressions were used for categorical outcomes and mixed-effects models were used for continuous outcomes. For consistency, effect sizes are presented as OR and 95% CI, regardless of whether the mental health outcome variable is continuous or categorical. High neuroticism, probable depression status, stress, type of stress, and mania were used as categorical outcomes, whereas the other mental health indicators were used as continuous outcomes. Covariates included age, sex, ethnicity, professional qualifications, employment status, unhealthy dietary intake, physical inactivity, smoking, and alcohol intake. Models with waist circumference and abdominal obesity as the exposure variables also adjusted for BMI. In the models, BMI, waist circumference, and body fat percentage were used as continuous variables, with BMI and waist circumference increasing by SD and body fat percentage increasing by 10%, whereas general obesity, abdominal obesity, and high body fat percentage were used as categorical variables. Life satisfaction and happiness scores were reverse scored, with higher scores indicating lower satisfaction with life or happiness. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. OR, odds ratio. [Color figure can be viewed at wileyonlinelibrary.com]

stress. A high body fat percentage was not associated with the risk of at least one stressor or mania. Apart from these findings, other results were consistent with those observed for general obesity.

The findings by sex are shown in Figures S4 and S5. The overall results are consistent with those of the total population, except that recent depressive symptoms were not associated with BMI in male individuals or with abdominal obesity in female individuals.

Summary of the bidirectional associations between mental health indicators and adiposity indicators

As shown in Figure 3, the longitudinal analyses confirmed the following bidirectional associations:

- BMI and general obesity with eight mental health indicators, including recent depressive symptoms, probable depression status, experiencing at least one type of stress (especially stress from serious illness, injury, or assault to oneself or financial difficulties), and life satisfaction (especially health satisfaction and financial situation satisfaction).
- Waist circumference and abdominal obesity with two mental health indicators, including recent depressive symptoms and financial situation satisfaction.
- Body fat percentage and high body fat percentage with four mental health indicators, including recent depressive symptoms, experiencing stress from financial difficulties, health satisfaction, and financial situation satisfaction.

The observed bidirectional associations between indicators of mental health and adiposity variables by sex were consistent with the overall results (Figure S6).

DISCUSSION

The present study is the first, to our knowledge, to systematically assess the bidirectional associations of indicators of general obesity,

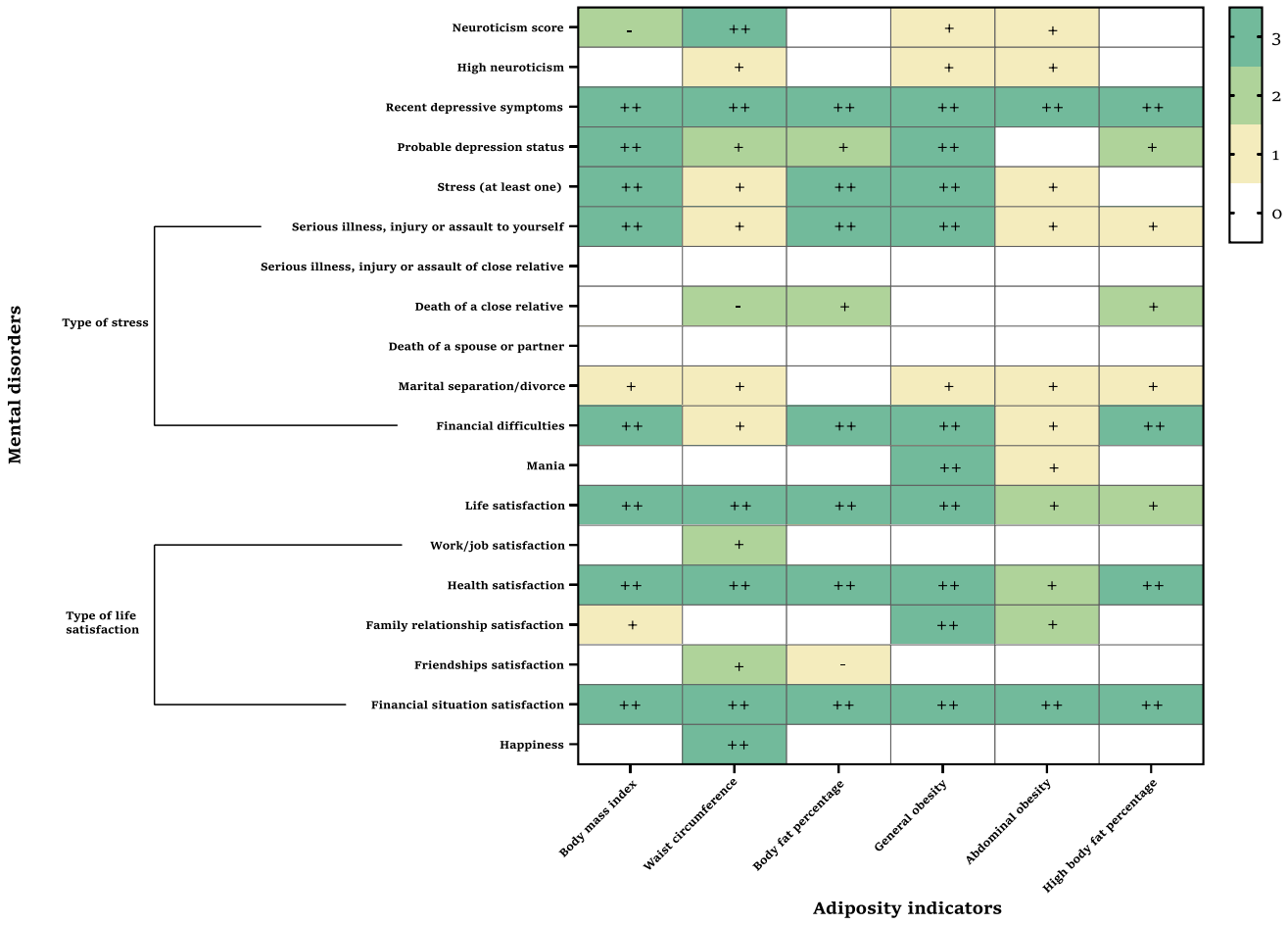


FIGURE 3 Summary of the bidirectional associations between mental health indicators and adiposity indicators. 0, no association observed; 1, the effects of mental health indicators on adiposity outcomes were significant; 2, the effects of adiposity indicators on mental health outcomes were significant; and 3, the bidirectional associations between mental health indicators and adiposity indicators were significant. "+" indicates a positive correlation, and "-" indicates a negative correlation. Life satisfaction and happiness scores were reverse scored, with higher scores indicating lower satisfaction with life or happiness. [Color figure can be viewed at wileyonlinelibrary.com]

abdominal obesity, and high body fat percentage with both positive and negative mental health indicators in a large-scale prospective cohort. These bidirectional associations varied by adiposity and mental health indicators. Our study identified bidirectional associations of BMI and general obesity with recent depressive symptoms; probable depression status; stress from serious illness, injury, or assault to oneself or financial difficulties; health satisfaction; and financial situation satisfaction. Waist circumference and abdominal obesity were bidirectionally associated with neuroticism score, recent depressive symptoms, and financial situation satisfaction. Furthermore, body fat percentage and high body fat percentage were bidirectionally associated with recent depressive symptoms, stress from financial difficulties, health satisfaction, and financial situation satisfaction. These findings underscore the importance of tackling both obesity and these mental health indicators to enhance the overall health and well-being of adults.

Our study contributes significantly to the existing literature by uncovering bidirectional associations between recent depressive symptoms and body fat percentage, alongside BMI and waist circumference, aligning with previous research findings [28]. These results may be explained by several mechanisms. First, obesity is recognized as a chronic inflammatory status [29] characterized by macrophage infiltration and subsequent secretion of inflammatory cytokines, such as tumor necrosis factor-α and interleukin-6 [30]. Chronic inflammation has been associated with the development of depression [31]. Conversely, depression is associated with elevated inflammatory makers [31], which have been associated with increased body fat percentage [32, 33]. Second, increased body fat can disrupt hormone regulation such as that of leptin and insulin [30], which in turn impact neurotransmission and mood regulation, consequently increasing the risk of depression [34]. Conversely, early symptoms of depression may be associated with insulin resistance [35], contributing to higher body fat percentage. Third, individuals with obesity often engage in unhealthy lifestyle behaviors, such as lack of physical activity, which are established risk factors for depression [36]. Conversely, depressive symptoms are also accompanied by lifestyle changes such as decreased physical activity and emotional eating [37, 38], leading to an increased risk of developing obesity. Additionally, medication use in individuals with depression, such as selective serotonin reuptake inhibitors and bupropion, may contribute to weight gain and exacerbate obesity [39]. In summary, obesity and depressive symptoms interact with each other, forming a vicious cycle.

We found that bidirectional associations exist between chronic stress, particularly stress from serious illness, injury, or assault to oneself or financial difficulties, and BMI and body fat percentage. Chronic stress activates the hypothalamic–pituitary–adrenal axis, resulting in elevated cortisol levels [40]. Cortisol plays a key role in fat storage, especially in abdominal fat [40]. A study by Tomiyama et al. found that chronic stress can contribute to unhealthy eating habits such as overeating and a preference for foods high in calories, fats, and sugars, ultimately resulting in weight gain and obesity [40]. Individuals or families under financial difficulties are more likely to adhere to such dietary habits, as financial stress may force them to choose inexpensive and energy-dense but nutrient-poor foods. These foods often contain high levels of sugar, fat, and salt, which can easily lead to excessive energy intake and weight gain [41]. Additionally, chronic stress has been associated with sleep disorders; insufficient sleep can impact appetite-regulating hormones such as leptin and insulin, leading to an increase in appetite and a slowdown in energy metabolism [40]. Conversely, individuals with general obesity or high body fat percentage may experience social discrimination and prejudice [42]. This obesity-related stigma increases vulnerability to psychological stress and can impact an individual's work performance and daily activities [43], further contributing to stress. Therefore, to better understand and address obesity, it is necessary to focus on the psychological stress and socioeconomic status of individuals.

Our study has revealed, for the first time, to our knowledge, that bidirectional associations consistently exist between financial situation satisfaction and all the adiposity indicators. Obesity was widely known to be associated with numerous health complications [44], which can impose significant financial burdens on individuals and their families. Moreover, chronic health concerns associated with obesity may impair one's ability to work efficiently, thereby affecting productivity and income levels and ultimately reducing satisfaction with one's financial situation [45]. Conversely, increased financial situation satisfaction often correlates with higher socioeconomic status. Individuals with elevated socioeconomic status tend to exhibit greater awareness of health-related behaviors and are more inclined to adopt healthier lifestyles, such as maintaining a balanced diet and engaging in regular physical activity [45]. These lifestyle choices could contribute to a reduced risk of developing obesity. Therefore, the approach to effectively address obesity should consider the economic and psychological status of individuals' lives. This entails providing educational resources, psychological support, financial assistance, and access to health care services to promote healthy eating habits and physical activity. This will break the negative cycle and promote the overall well-being of individuals.

The clinical implications of our findings are profound, as they highlight the need for integrated approaches in addressing both mental health and adiposity. The bidirectional associations among recent depressive symptoms, stress, health satisfaction, and adiposity suggest that treating one condition may help alleviate the other. For example, reducing depressive symptoms through psychological therapies may help improve weight management by reducing emotional eating and increasing motivation for physical activity. Similarly, managing obesity through lifestyle interventions, such as diet and exercise programs, could contribute to improvements in depressive symptoms and stress. Furthermore, the bidirectional relationships of stress from financial difficulties and financial situation dissatisfaction with obesity indicators underscore the importance of considering socioeconomic factors in clinical interventions. Health care providers should screen for and address recent depressive symptoms, stress, life satisfaction, and obesity risk factors simultaneously. This strategy is crucial for more effectively improving the overall health and well-being of adults.

Our study has several limitations. First, the sample sizes for mania ($n = 207–376$), following the exclusion of noncompliant participants,

were relatively small, which compromises the reliability of the multivariate logistic regression and mixed-effects results. Second, the UK Biobank assesses manic symptoms within a 2-day time frame, which does not align with the *Diagnostic and Statistical Manual of Mental Disorders* (Fifth Edition) (DSM-5) diagnostic criteria for mania, which require the symptoms to persist for at least 1 week. This discrepancy may lead to an overestimation of the prevalence of mania. Third, mental health data were self-reported through touch screen questionnaires, which may be subject to recall bias. Fourth, the generalizability of our findings should be interpreted with caution, as the participant cohort is predominantly White and relatively older with an average age of 57 years. Furthermore, significant differences in background characteristics exist between participants who completed at least one follow-up assessment and those who did not (Table S2). Therefore, caution should be taken when generalizing our findings to younger populations or other ethnic groups. Fifth, the cumulative effects of obesity on mental health indicators were not considered in the current study. Future research should include large-scale cohort studies to examine these cumulative effects, further elucidating the bidirectional associations between indicators of adiposity and mental health.

CONCLUSION

In conclusion, bidirectional associations between adiposity indicators and mental health indicators depend on the type of adiposity indicators. Consistently, bidirectional associations among recent depressive symptoms, financial situation satisfaction, and indicators of general obesity, abdominal obesity, and high body fat percentage were observed. Additionally, stress and health satisfaction were bidirectionally associated with indicators of general obesity and high body fat percentage. Probable depression status was bidirectionally associated with indicators of general obesity. By delineating the intricate interplay between adiposity and mental health across diverse domains, our study offers valuable insights that can inform targeted interventions and public health strategies aimed at improving overall well-being in the general population.O

AUTHOR CONTRIBUTIONS

Lu Ma and Meng Lv developed the concept and analysis plan. Meng Lv accessed, verified, and analyzed the data. Meng Lv and Lu Ma interpreted the data. Meng Lv and Lu Ma drafted the manuscript. Meng Lv, Lu Ma, Lei Zhang, Ying Li, and Zihan Guo edited the manuscript. All authors had access to the data and accept responsibility for submitting the article for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declared no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from UK Biobank. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from https://www.ukbiobank.ac.uk/ with the permission of UK Biobank.

ORCID

Meng Lv https://orcid.org/0009-0006-8568-7498
Ying Li https://orcid.org/0000-0002-0572-5444
Lu Ma https://orcid.org/0000-0002-6265-5032
Lei Zhang https://orcid.org/0000-0003-2343-084X

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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