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Research paper

Internalising problems and self-reported BMI/physical health: Correlated genetic and environmental influences versus probable causal mechanisms

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ABSTRACT

Internalising problems (depressive and anxiety symptoms) are associated with poor physical health indices. This may reflect causal mechanisms or shared genetic and environmental factors but this has not been previously tested. We tested whether indirect relationships between internalising problems and physical health indices though health behaviours and poor sleep quality were better explained by genetic and environmental correlations. The sample comprised participants in the UK Twins Early Development Study cohort at ≈22 years (9697 and 8718 participants of whom 38.2 % were male, 55.6 % from low socioeconomic backgrounds and 95.5 % were white). Participants were assessed for internalising symptoms, health behaviours, sleep quality, BMI and self-rated health. We compared three twin genetic models to determine whether genetic and environmental correlations versus mediation were a better explanation for phenotypic relationships; and for the best genetic model, we tested differences by sex, socioeconomic status and high versus normal BMI. Although, health behaviours and sleep quality appeared to mediate the phenotypic associations between internalising problems and physical health, genetic and environmental correlations emerged a better explanation for observed associations; and these correlations were stronger in those with high BMI. We concluded that poor health behaviours and sleep quality are relevant to understanding the aetiological links between internalising problems and elevated BMI, especially among those who are overweight or obese. Causal mechanisms alone appear insufficient to explain the links between internalising problems and physical health outcomes. Future research should incorporate genetic information in investigating these relationships.

1. Introduction

Depression and generalised anxiety are the most common mental health disorders (WHO, 2017) and are leading causes of morbidity (Vos et al., 2016). Both disorders and their symptoms (which constitute internalising problems) are also associated with poorer self-rated physical health (subsequently referred to as self-rated health; Gaynes et al., 2002) and high Body Mass Index (BMI, De Wit et al., 2009). In turn, high BMI alongside internalising problems are recognised risk factors for cardiometabolic conditions and mortality (Everson et al., 2002; Koliaki et al., 2019; Lyall et al., 2017).

Proposed mechanisms of the link between internalising problems and physical health include health behaviours such as physical inactivity, poor dietary habits, and reduced sleep quality. These variables are associated with internalising problems and higher BMI/lower self-rated quality of life (Faith et al., 2002; Maugeri et al., 2018; Romain et al., 2018; Strine et al., 2005; Tan et al., 2018; Yu et al., 2016). Specifically, internalising problems could increase BMI or worsen self-rated health through unhealthy behaviours like physical inactivity and unhealthy diets (Ohrnberger et al., 2017). Another potential pathway is through

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poor sleep quality which can promote weight gain through increased cortisol production (Spiegel et al., 1999). Alternatively, we recognise that BMI/poor self-rated health can also cause or worsen internalising problems through similar mechanisms. However, we considered that cardiometabolic complications often manifest later in life (Tsay et al., 2016) while the focus of the present analyses is on young adults. Hence, we specified internalising problems as influencing BMI/self-rated health in expectation that the effect of mental on physical health may be more prominent in a younger compared to older age group. We, however, also note that our analytic models do not test the direction of causation; rather, they indicate probable causal pathways which require more specific approaches to determine the direction of causality.

Genetically informative approaches such as Mendelian Randomisation (MR) have been used to specifically investigate separate cross-sectional causal (including bidirectional) links between internalising problems as predictors, and health behaviours, sleep quality, and BMI as outcomes. However, findings from this line of enquiry have been mixed. Using MR, some studies found significant causal influences of psychological distress on higher BMI (e.g., Lawlor et al., 2011) while a few found weak causal effects of BMI on depression (e.g., Hartwig et al., 2016; Tyrrell et al., 2019). Finally, some studies did not find any causal associations between internalising behaviours and BMI (e.g., Hung et al., 2014; Pistis et al., 2021). In the latter two instances, the authors suggested that their negative findings may reflect correlated genetic and environmental influences rather than causal effects as the true explanation for observed phenotypic associations.

Indeed, several studies have separately demonstrated genetic and environmental correlations between internalising problems, health behaviours, sleep quality, BMI and self-rated physical health (e.g., Gregory et al., 2011; Herle et al., 2020; Wang et al., 2022). However, these studies did not compare the relative significance of genetic and environmental correlations versus causal mechanisms in the reported associations between these variables. This line of enquiry is especially crucial considering negative findings from MR studies which aim to determine causality. If health behaviours and/or poor sleep truly mediate the relationships between internalising symptoms and physical health indices (i.e., reflecting true causal mechanisms), then interventions to improve physical health and/or sleep among those experiencing mental health difficulties can be targeted at lifestyle modification. This is likely to be even more useful if the indirect causal (mediation) relationships are independent of genetic and/or environmental confounding. In contrast, if genetic and/or environmental correlations are a better explanation, then future work should be focused on identifying common underlying genetic and environmental risk exposures which can respectively serve as risk indicators or be targeted for interventions.

Using biometric genetic analyses, we compared genetic models to test whether any phenotypic indirect effects were confounded by shared genetic and environmental influences i.e., whether models specifying shared genetic and/or environmental influences are a better explanation for observed correlations than causal processes. We hypothesised that internalising problems would be indirectly associated with BMI and self-rated health through health behaviours and poor sleep quality. As previous studies had demonstrated genetic and environmental correlations between the study variables, we expected that the proposed mediation relationships may be confounded by genetic and environmental correlations between internalising problems, health behaviours, and physical health.

We secondarily investigated whether there were differences by sex, socioeconomic status (SES) and BMI category (i.e., normal versus high) in the best-fitting genetic models. This was based on evidence showing that internalising problems and health risk behaviours/poor sleep quality are higher among females and males, respectively (Abuladze et al., 2017; Altemus et al., 2014), and all together among individuals from lower socioeconomic backgrounds (Ciciurkaite and Perry, 2018; Everson et al., 2002). Internalising problems are also non-linearly associated with BMI, whereby both low and high BMI are associated with higher depressive symptoms while normal BMI has the weakest association with BMI (De Wit et al., 2009). We expected that the phenotypic correlations between internalising problems, health behaviours, and physical health would be stronger in female participants, those from low socioeconomic backgrounds, and those with high BMIs. We had no hypotheses about how the genetic and environmental influences would vary based on these variables.

2. Methods

2.1. Sample

The sample comprised twins who participated in the age 21 wave of the TEDS cohort. Data were collected in two phases between June 2017 and February 2019 when the twins were aged 20.5–23.5 years. Of the 16,810 participating families originally contacted; data were collected using mailed paper booklets, a mobile phone application, and a web-based platform. There were 9697 and 8718 participants in the first and second phases of data collection respectively (response rates of 56.1 % and 61.5 % respectively – non-participants in phase 1 were not contacted in phase 2); with 93.5 % being from white ethnic backgrounds (Lockhart et al., 2023). Analyses were based on participants who had BMI data ($n = 8579$). Those with BMI missing were more likely to be male, have better socioeconomic status, higher levels of emotional problems, depressive and anxiety symptoms, poorer dietary habits, greater physical inactivity, poorer sleep quality and poorer self-rated physical health though the effect sizes were small (Supplementary Tables S1a and S1b). TEDS participants with non-missing data were also more likely to have higher educational qualifications (Lockhart et al., 2023). Participants with extremely low BMI scores (BMI < 18.5 kg/m^2; $n = 629$) were excluded to reduce confounding by severe medical conditions and anorexia nervosa (De Wit et al., 2009).[1] The present sample comprised 2010–2960 complete twin pairs per variable of which 819–1167 were monozygotic and 1191–1793 were dizygotic twins (Supplementary Table S2). Further details of recruitment are available from the TEDS website (https://www.teds.ac.uk/datadictionary/studies/21yr.htm) and from previous descriptions (Haworth et al., 2013; Oginni et al., 2022; Rimfeld et al., 2019). Zygosity was assessed during childhood using parental reports of physical similarity, which correctly identified 95 % of twins when compared to DNA testing (Price et al., 2000). Ethical approval was provided by the King's College London Ethics Committee (reference: PNM/09/10–104); and informed consent obtained from participants prior to data collection.

2.2. Measures

Sociodemographic variables: Age (in years) and sex at birth were each assessed using single questions and included as confounders in all analyses. Socioeconomic status (SES) was assessed as a composite of the participants' parents' highest level of education (scored from 1 [No qualification] to 8 [higher degree or postgraduate qualification] for each parent), and annual household income (scored 1 [£5000] to 11 [>£100,000]). Each SES measure was standardised, summed and standardised again with higher scores indicating higher SES. For secondary analyses (see below), SES was dichotomised into low (those scoring '≤0') versus high SES (those scoring >0).

[1] This exclusion was further justified by the negatively sloped tail of the U-shaped relationship between BMI and each of the internalising problems domains in our sample which indicated higher internalising problems among those with extremely low and higher BMIs (Supplementary Fig. S1). This group also reported higher mental health symptoms and poorer sleep quality and subjective physical health (Supplementary Table S1c) but the small subsample size precluded further analyses.

2.2.1. Internalising symptoms (the predictor)

Depressive and anxiety symptoms, and emotional problems. Depressive symptoms over the past two weeks were rated using an 8-item version of the original 13-item Brief Short Moods and Feelings Questionnaire (Angold et al., 1995). Items such as "I feel miserable and unhappy" were each rated on a 3-point Likert scale ranging from 0 (Not true at all) to 2 (Very true).

Anxiety symptoms in the past week were rated using the 10-item Generalised Anxiety Disorder measure (Craske et al., 2013). Items were each rated on a 5-point Likert scale ranging from 0 (Never) to 4 (All of the time). A sample item was "I have felt anxious, worried, or nervous".

Emotional symptoms over the past six months were rated using the 5-item Emotional problems subscale of the Strengths and Difficulties Questionnaire (Goodman, 1997). Sample items include "being nervous in new situations and easily losing confidence" and each item was rated on a 3-point Likert scale ranging from 0 (Not true) to 2 (Certainly true).

All the questionnaires were self-rated, and total scores were derived by summing the responses to the individual items with higher scores indicating higher depressive and anxiety symptoms, and emotional problems. The Cronbach's alphas for all three measures in the present study were 0.87, 0.92 and 0.79 respectively which were consistent with previous reports (Oginni et al., 2022; Toseeb et al., 2022).

2.2.2. Health behaviours and sleep quality (proposed mediators)

Health behaviours comprised poor dietary habits and physical inactivity. Diet was assessed using a 12-item version of the Rapid Eating and Activity Assessment for Patients which originally comprised 20 items (Gans et al., 2006). Six questions each measured the usual daily frequency of eating healthy (e.g., whole grain products, fruits and vegetables) and unhealthy foods (e.g., salted snacks, fried foods and sweets) respectively. The responses were rated on a 5-point Likert scale ranging from 0 (Rarely) to 4 (Everyday). The responses to the six healthy eating items were reverse-scored and all responses summed with higher scores indicating higher levels of unhealthy eating. The internal consistency in the present study was 0.68.

Physical inactivity was assessed using three items designed by the TEDS team. These questions assessed the frequency of physical activity in a typical week including strenuous exercise like running or jogging (question 1), moderate exercise like walking fast (question 2) and mild exercise requiring minimal effort like bowling (question 3). Each item was rated on a 5-point Likert scale ranging from "0–15 min" (scored 1) to "More than 3 hours" (scored 5). Weightings of 3, 2 and 1 were respectively applied to questions 1, 2 and 3, to assign greater importance to more strenuous exercise. The mean of the weighted scores was derived, standardised and multiplied by −1 so that higher scores indicated less physical activity. Internal consistency in the present study was 0.60.

Sleep quality was assessed using 8 of the 19 items of the Pittsburgh Sleep Quality Index (Buysse et al., 1989) which rate sleep quality over the prior month. This comprised the last 8 options (i.e., c–j) of question 5 which enquired about the frequency of sleep disruptions such as waking up in the middle of the night. Each item was rated on a 4-point Likert scale ranging from 0 (Not during the past month) to 3 (Three or more times per week). The responses to the individual items were summed and used in analyses with higher scores indicating poorer sleep quality. The Cronbach's alpha in the present study was 0.72.

2.2.3. BMI and self-rated physical health (separate outcomes)

BMI was derived as a ratio of self-reported weight (kilograms) to the square of self-reported height (metres) at age 21 years; higher scores indicated an increasing tendency towards being overweight or obese. The correlation between self-reported and directly observed BMI ranges between 0.97 and 0.99 (Hodge et al., 2020) suggesting that self-reports are a valid measure of BMI. For secondary analyses, BMI was categorised into normal and high BMI (BMI of 18.5-25 kg/m^2 and $\geq$25 kg/m^2 respectively). This was based on the differential relationship between BMI and internalising problems among those with normal versus high BMI in exploratory analyses (the slopes were nearly completely horizontal and positive in both groups respectively; Supplementary Fig. S1).

Self-rated physical health was assessed using five questions from the SF-36 Health Survey (Ware Jr and Gandek, 1998). The responses were given on a 5-point Likert scale (1–5) and a sample item was "In general, how would you say your health is?" These questions were supplemented with two separate questions eliciting the frequency of lifetime and past-year hospitalisations with responses ranging from "No" (scored 1) through "Yes, 2-4 times" (scored 3) to "Yes, 8+ times" (scored 5). The first five responses were reverse-scored and summed with the responses to the latter two questions with higher scores indicating poorer self-rated physical health. The Cronbach's alpha for all 7 questions was 0.69.

2.3. Analyses

2.3.1. Phenotypic analyses

Data cleaning, preparation and descriptive statistics were carried out using SPSS (version 28) and STATA (version 14) while structural equation modelling including twin analyses were carried out using OpenMx in R (Neale et al., 2016). We inspected the phenotypic correlations between the observed variables to inform the specification of latent factors in structural equation models. We specified five latent factors for the different phenotypes of interest: internalising problems (depressive and anxiety symptoms and emotional problems, r ranged between 0.55 and 0.72; Supplementary Table S2), health behaviours (poor dietary habits and physical inactivity, $r = 0.35$), poor sleep quality, BMI and self-rated physical health (the latter three were single-indicator latent factors). The construction of these latent factors was based on theory and at least moderate correlations between the constituent measured variables (Bollen and Lennox, 1991). Specifically, the correlations between depressive and anxiety symptoms and emotional problems ranged between 0.55 and 0.72 while that between poor dietary habits and physical inactivity was 0.35 (Supplementary Table S2). Finally, we investigated correlations between the latent factors.

2.3.2. Biometric genetic models

We parsed the variances and covariances between the latent factors into genetic and environmental components by comparing similarities in monozygotic versus dizygotic twins using the classical twin design (Rijsdijk and Sham, 2002). The additive genetic factor (A) reflects the sum of genetic loci across the whole genome, while shared (C) and nonshared (E) environmental influences make family members similar to and different from one another respectively, with the latter including measurement error (Neale and Cardon, 2013; Rijsdijk and Sham, 2002).

To test whether correlated genetic (and/or environmental influences fit the data better than causal mechanisms; see Supplementary Methods), we compared three biometric genetic models (Rosenström et al., 2019; Fig. 1). First, we fitted a multivariate Cholesky decomposition which is the most saturated genetic model because it parses all the variances and covariances into the maximum number of ACE components. We report the correlated factor solution (Loehlin, 1996) as we were agnostic about the direction of effects. Second, we fitted a common factor–independent pathway model. This assumes that all the covariances between the factors of interest are due to a single common set of shared ACE influences alongside factor-specific ACE influences. Finally, we fitted a biometric mediation model. This specifies probable causal mediation paths between the predictor, mediator, and outcome factors along with factor-specific A, C and E components (Oginni et al., 2022; Rosenström et al., 2019; Fig. S2, Supplementary material). We note that although we placed health behaviours before poor sleep quality (Damgaard et al., 2024; Wang and Boros, 2021) in the biometric mediation model, this model does not test the direction of causal effects.

Both the Cholesky decomposition and the common factor–independent pathway models indicate that the observed phenotypic relationships reflect varying degrees of correlated genetic and/or

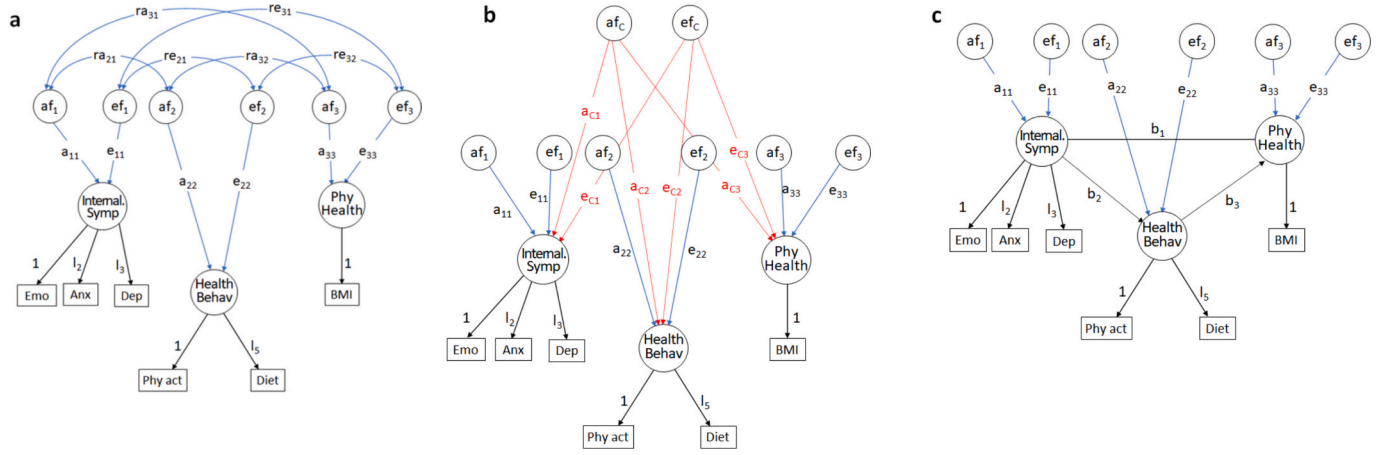

Fig. 1. Path diagrams depicting biometric genetic models: the Cholesky decomposition (a), the Common-factor independent pathway (b) and the Biometric mediation (c) models. Observed variables: Emo = emotional problems, Anx and Dep = anxiety and depressive symptoms, BMI=Body-Mass Index; Latent factors: Internal. Symp = internalising symptoms, Health Behav = health behaviours, Phy Health = physical health; $l_{2\text{-}10}$ = factor loadings (loading of first indicator of each variable constrained to 1 for identification); af_{1-3} and ef_{1-3} = additive genetic (A) and individual-specific environmental (E) influences on latent factors; a_{11}, a_{22}, a_{33} (and e_{11}, e_{22} and e_{33}) = their respective path coefficients (blue lines); ra_{21}, ra_{31} and ra_{32} (and re_{21}, re_{31} and re_{32}) = correlations between A (and E) influences on the latent factors (blue lines); af_c (and ef_c) = common A (and E) influences on the latent factors; a_{C1}, a_{C2} and a_{C3} (and e_{C1}, e_{C2} and e_{C3}) = their path coefficients (red lines); b_{1-3}-causal paths between latent factors. Shared environmental influences (C) and Sleep are omitted to facilitate clarity. These models were specified separately for Self-Rated Physical Health as the subjective physical health measure. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

environmental influences. In contrast, the biometric mediation model indicates that phenotypic correlations are better explained by causal mechanisms. Thus, if either the Cholesky decomposition or the common factor-independent pathway model emerge as the best-fitting model, this would suggest that causal mechanisms are not a sufficient explanation for the phenotypic associations i.e., causal links previously reported are potentially confounded by shared genetic and/or environmental influences. As these genetic models were non-nested, their fit was compared using the Akaike Information Criterion (AIC) with the lowest AIC indicating the best model (Anderson and Burnham, 2002).

2.3.3. Secondary analyses

The best genetic model was further re-specified as sets of heterogeneity models in which the genetic and environmental influences were allowed to vary by birth sex (males vs females), SES (low vs high) and BMI categories (normal vs high). Each of these models was then compared to the corresponding homogeneity model in which the parameter estimates were constrained to be equal across the two groups. Homogeneity models were nested within the corresponding heterogeneity models, and so fits were compared using Chi-squared tests. The most parsimonious model was selected as the best-fitting model.

We pre-registered all analyses (https://osf.io/78qdr/), but made some minor changes to the analysis plan based on some preliminary results. Specifically, we excluded substance use variables due to their small and inconsistent associations with the other variables. We investigated differences by BMI categories based on nonlinear associations between internalising problems and BMI (Supplementary Fig. S1). Finally, we did not incorporate dichotomised BMI as an outcome in mediation analyses because we demonstrated genetic and environmental confounding.

All analyses were carried out using Full Information Maximum Likelihood which handles missing data by using all available datapoints (Enders and Bandalos, 2001).

3. Results

3.1. Phenotypic analyses

3.1.1. Descriptive statistics

The mean age of the participants was 22.3 (±0.91) years (Table 1),

Table 1
Descriptive statistics in the total sample.

Variable	Mean[a]/n[b]	SD[a]/%[b]	Skew[c]	Skew[d]
Age (years)[a]	22.28	0.91	0.10	–[e]
Sex[b]			–	–
Male	3039	38.2		
Female	4911	61.8		
SES[b] (n = 6631)			–	–
Low SES	2942	55.6		
High SES	3689	44.4		
Internalising problems				
Emotional problems[a]	3.50	2.67	0.53	–[e]
Depressive symptoms[a]	4.33	4.05	1.07	–[e]
Anxiety symptoms[a]	7.12	7.11	1.60	0.01
Health behaviours				
Poor dietary habits[a]	22.52	6.59	0.12	–[e]
Physical inactivity[a]	−0.05	1.00	−0.13	–[e]
Poor sleep quality[a]	4.80	3.78	1.11	−0.77
Objective/subjective health indices				
Self-rated physical health[a]	16.03	3.80	0.52	–[e]
BMI (kg/m^2)[a]	23.86	4.22	1.67	0.03
Categorised BMI[f]			–	–
Normal BMI	5709	71.8		
High BMI	2241	28.2		

Note. SES=Socioeconomic status; BMI=Body Mass Index. The ranges of scores obtainable for the study variables are as follows: Emotional problems (0–10), Depressive symptoms (0–16), Anxiety symptoms (0–40), Poor dietary habits (0–48), Physical inactivity (6–30 but z-transformed and multiplied by −1), Poor sleep quality (0–24), Self-rated physical health (7–35), and BMI (18.5–51.5; BMI < 18.5 excluded from analyses).

[a] Mean and standard deviation (SD) stated.
[b] Sample size (n) and percentage stated.
[c] Before log transformation.
[d] After transformation.
[e] No transformation carried out.
[f] BMI dichotomised using cut-off of ≥25 kg/m^2.

61.8 % were female and 44.5 % were from higher socioeconomic backgrounds. The means and standard deviations of the main study variables are given in Table 1. These differed significantly by sex, SES and BMI category (Supplementary Table S1). Specifically, emotional problems, depressive and anxiety symptoms were higher; and sleep quality and self-rated health poorer among females, individuals with low SES and those with high BMI. BMI was higher among females and those with low SES while physical inactivity was higher in males, those with low SES and those with high BMI.

3.1.2. Factor correlations

The latent factors were all positively and significantly correlated with each other (Table 2). Specifically, both higher BMI and poorer self-rated health were associated with higher internalising problems, poorer health behaviours and sleep quality (r ranged from 0.08 [95 % CI; 0.05, 0.10] to 0.46 [95 % CI: 0.44, 0.48]). The correlations with self-rated health were larger compared to those with BMI.

3.2. Biometric genetic models

3.2.1. Model comparisons

A comparison of the biometric genetic models incorporating BMI and self-rated health as separate outcomes indicated that the best-fitting model for both factors was the Cholesky decomposition model. The Cholesky models had the lowest AICs for both BMI and self-reported health (154,586.6 and 155,151.7 respectively) compared to the common factor independent pathway (154,638.9 and 155,235.1 respectively) and biometric mediation (154,639.3 and 155,184.1) models (Supplementary Table S5). Thus, genetic and environmental correlations explained the phenotypic associations better than probable causal (including mediation) effects.

3.2.2. Cholesky decomposition (correlated factor solution)

Of the five latent factors in the present study, heritability was lowest for poor sleep quality (27 %) and much larger for health behaviours (67 %) and BMI (73 %; see Fig. 2 for 95 % confidence intervals). The heritability estimates for self-rated health and internalising problems were intermediate (32 % and 44 % respectively). There were significant genetic correlations between internalising problems and both health behaviours (r_a = 0.45) and poor sleep quality (r_a = 0.74). That between health behaviours and sleep quality was smaller (r_a = 0.14). Similarly, there were significant nonshared environment correlations between internalising problems and both health behaviours and poor sleep quality (r_e = 0.12 and 0.30), while that between the latter two factors was near zero and not statistically significant.

Table 2
Correlations between latent factors in the study sample.

Variables	Internalising problems (1)	Health behaviours (2)	Poor sleep quality (3)	BMI (4)	SRPH (5)
(1)	1				
(2)	0.30 (0.26, 0.33)	1			
(3)	0.45 (0.43, 0.47)	0.07 (0.04, 0.11)	1		
(4)	**0.08 (0.05, 0.10)**	**0.12 (0.08, 0.15)**	**0.08 (0.05, 0.10)**	1	
(5)	**0.46 (0.44, 0.48)**	**0.45 (0.42, 0.48)**	**0.27 (0.24, 0.29)**	0.12 (0.10, 0.14)	1

Note. BMI = Body Mass Index; SRPH = Self-rated physical health; Internalising problems factor indicated by depressive, anxiety and emotional symptoms; Health behaviours factor indicated by physical inactivity and poor dietary habits; Correlation coefficients of BMI and SRPH with the other variables are in bold to emphasise our focus on these relationships.

The genetic correlations between BMI and the other factors (r_a = 0.14–0.18) were smaller compared to those for self-rated health (r_a = 0.51–0.67). All the nonshared environment correlations between BMI and the other factors were less than 0.05 and not statistically significant (which may reflect the small phenotypic correlations with BMI), whereas those for self-rated health were larger and significant (r_e = 0.16–0.39). As an alternative, we report the proportion of the phenotypic correlations explained by additive genetic and nonshared environmental influences (Supplementary Tables 6a and 6b).

3.3. Secondary analyses

Preliminary exploratory analyses indicated significant differences in almost all variables by sex, socioeconomic status and BMI category. Specifically, all study variables apart from poor dietary habits were significantly higher among participants who were female, from lower socioeconomic backgrounds and had higher BMI (Supplementary Table S3). Notably poor dietary habit scores were significantly higher among male participants.

Further genetic analyses indicated significant differences by sex, SES and BMI categories for the Cholesky models incorporating BMI and self-rated health (Supplementary Table S7). Of these, the main differences were found in the BMI heterogeneity models (Fig. 3), whereby the genetic and environmental correlations with BMI were larger among participants with high compared to normal BMIs.

4. Discussion

Internalising problems were significantly associated with higher BMI and poorer self-rated health, and all three phenotypes were each in turn associated with the mediators (poor health behaviours and poor sleep quality). Indirect effects preliminarily explained 81 % and 28 % of the associations between internalising problems and BMI and self-rated health respectively. However, the Cholesky decomposition emerged as the best-fitting explanation for both. Thus, correlated genetic and environmental influences rather than (in)direct causal relationships were a better explanation for the observed associations. Notably, the phenotypic and genetic correlations between BMI and the other factors were stronger among participants with high BMI.

4.1. Phenotypic relationships

The significant phenotypic correlations between internalising problems, higher health risk behaviours, poor sleep quality and higher BMI/poorer self-rated health are consistent with previous research (Burnatowska et al., 2022; Carraça et al., 2021; Geiker et al., 2018; Romain et al., 2018; Schuch et al., 2017; Tan et al., 2018).

4.2. Correlated genetic and environmental influences versus probable causal mechanisms

We extended current knowledge by demonstrating for the first time that correlated genetic and environmental influences were a better explanation than causal (including mediation) mechanims for the observed associations between internalising problems, health behaviours, poor sleep quality and BMI/self-rated health. Previous research had demonstrated significant bivariate genetic and/or environmental correlations between the study variables (Gregory et al., 2011; Lind et al., 2017; Wang et al., 2022); however, none of these studies specifically tested mediation as alternative mechanisms. Our findings are consistent with prior studies which did not find causal links between internalising problems and health behaviours like diet, and BMI/self-rated health (Cole et al., 2020; Hughes et al., 2022; Hung et al., 2014; Walter et al., 2015). Our findings also substantiate suggestions that shared genetic influences are alternative explanations for the observed associations between the variables (Milaneschi et al., 2019; Walter et al.,

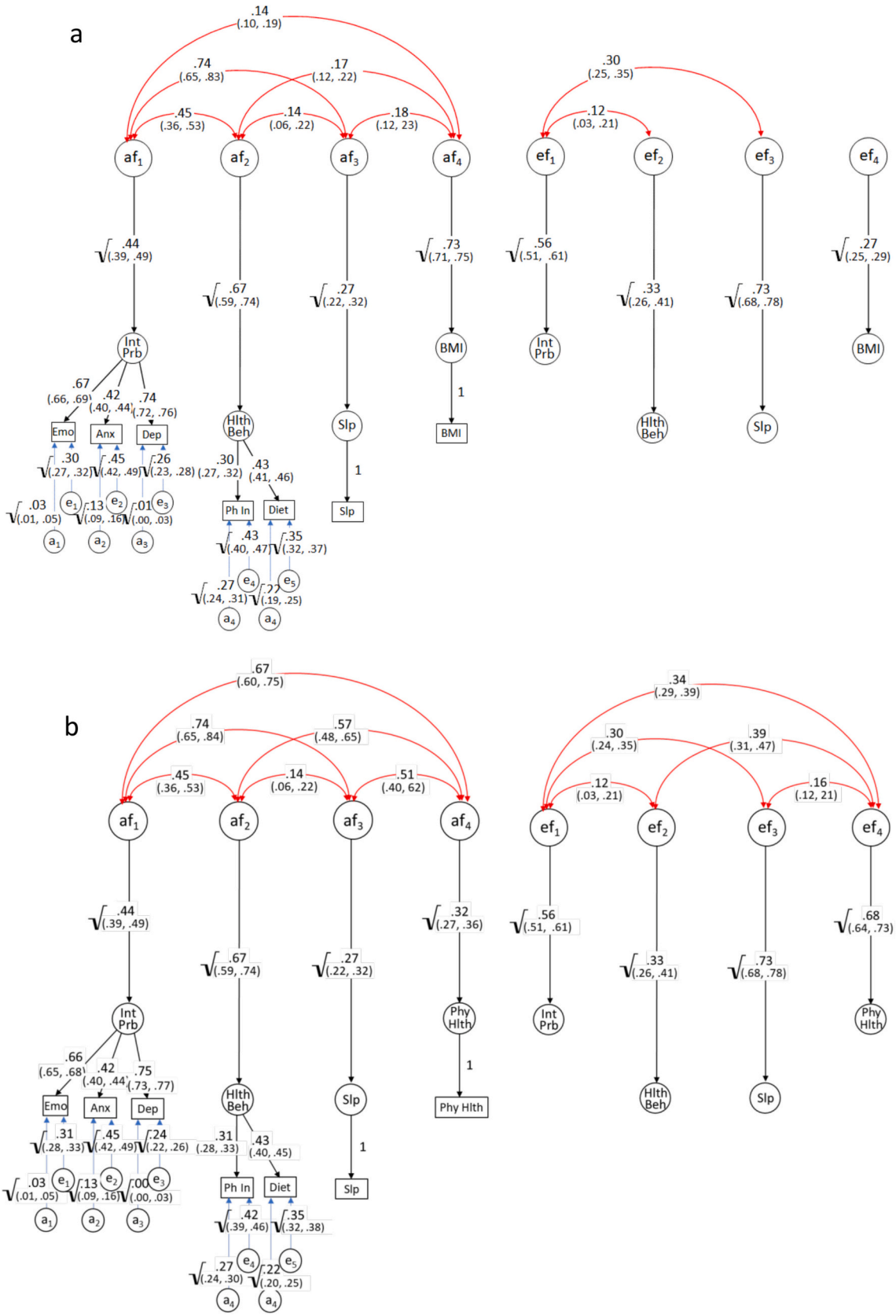

Fig. 2. Correlated factor solutions of Cholesky decomposition models for BMI (a) and self-rated physical health (SRPH, b). af_1, af_2, af_3 and af_4 = additive genetic influences respectively on the latent factors; ef_1, ef_2, ef_3 and ef_4 = individual-specific environmental influences on the latent factors; red double-headed arrows represent correlation paths between $af_{1–4}$ and $ef_{1–4}$; $a_{1–4}$, $e_{1–4}$ = standardised residual additive genetic and individual-specific environmental influences respectively on the indicator variables; omitted correlation paths indicate coefficients less than 0.05 and not statistically significant. Please see Supplementary Tables S6a and S6b for an alternative depiction of these results. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

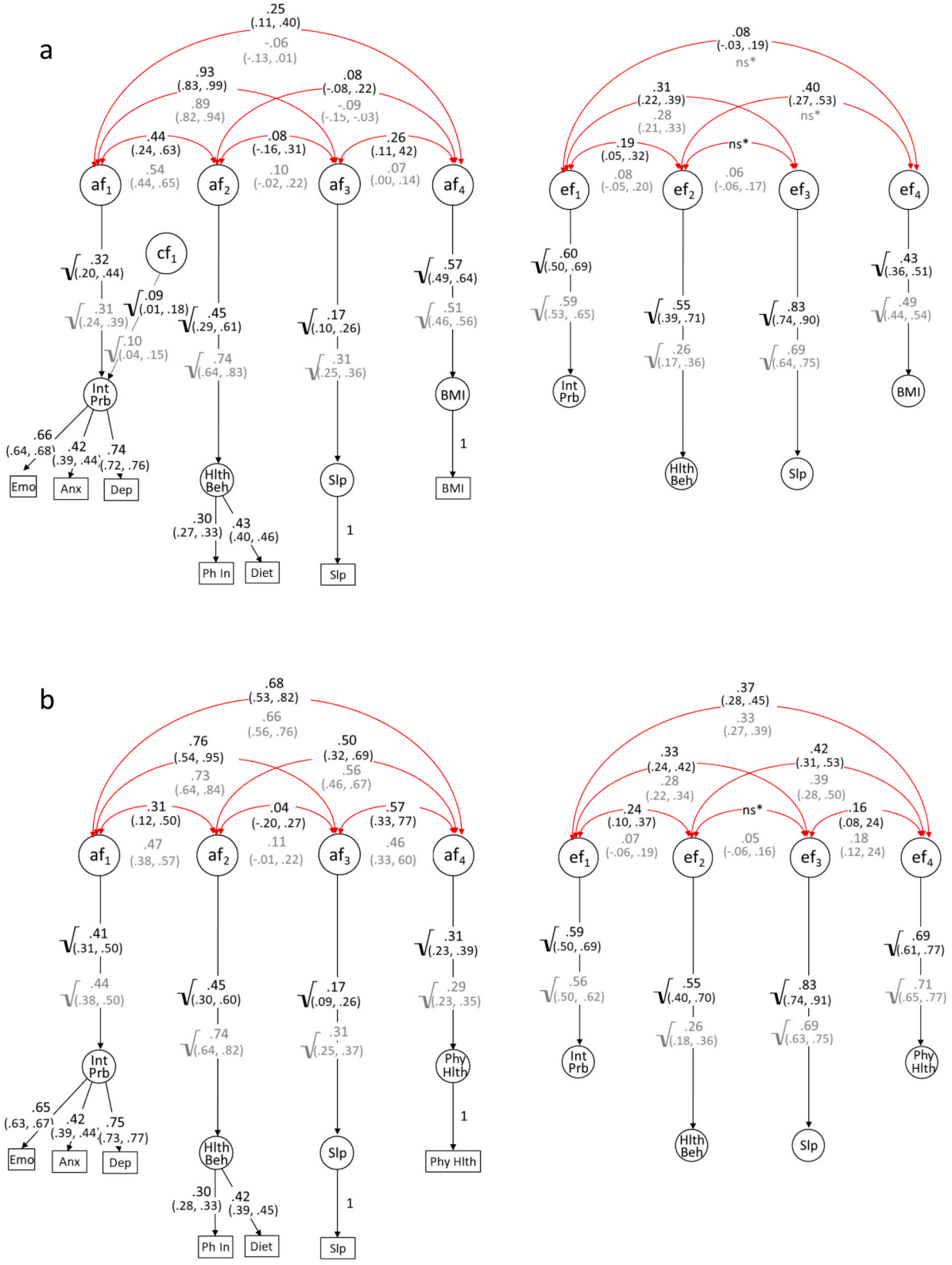

Fig. 3. Correlated factor solutions of Cholesky decomposition models for BMI (a) and self-rated physical health (Phy Hlth, b) depicting differences by BMI status (i.e., normal versus high BMI). af_{1-4}, cf_1, ef_{1-4} = additive genetic, shared and individual-specific environmental influences respectively on the latent factors; double-headed arrows represent correlation paths between af_{1-4} and ef_{1-4}; residual additive genetic shared and individual-specific environmental influences on the indicator variables are omitted for clarity, these are reported in Tables S6ci and S6cii; black text = estimates for participants with high BMI; grey text = estimates for participants with normal BMI; ns* = coefficients less than 0.05 and not statistically significant; omitted correlation paths indicate coefficients less than 0.05 and not statistically significant in both comparison groups.

2015).

The stronger phenotypic associations with BMI among those with higher compared to normal BMIs are consistent with the literature (De Wit et al., 2009; Jung et al., 2017). Considering that the phenotypic, genetic and individual-specific environmental correlations were almost completely attenuated among participants with normal BMI, the stronger genetic and individual-specific environmental correlations among them suggests that these aetiological influences are most relevant among those with high BMIs. Thus, the genetic factors influencing high BMI may simultaneously predispose overweight and obese individuals to internalising problems, unhealthy lifestyle habits and poor sleep quality. These aetiological correlations may also reflect genetic and individual-specific processes like stress and inflammation which impact on biological pathways influencing weight gain, internalising symptoms and sleep regulation (Faith et al., 2002; Geiker et al., 2018). Weight stigma (Emmer et al., 2020; Warnick et al., 2022) may also represent an individual-specific psychological process which simultaneously influences internalising symptoms and BMI (Emmer et al., 2020).

The absence of significant differences by sex and SES suggests that the genetic and environmental influences on the relationships with BMI/self-rated health are independent of both sex and SES.

4.3. Clinical implications

Our findings suggest that the management of internalising symptomatology among overweight and obese individuals must incorporate lifestyle habits and focus on sleep and BMI. This is consistent with research showing links between depression (an internalising disorder), obesity and their treatment outcomes. Firstly, untreated depression predicts poorer response to behavioural and surgical interventions for obesity and being overweight (i.e., high BMI; Legenbauer et al., 2009). Depression in obese individuals is more likely to be resistant to antidepressant treatment alone (Vogelzangs et al., 2011). Finally, behavioural interventions to improve BMI and health behaviours are independently associated with improvement in internalising symptomatology (Pagoto et al., 2013). Thus, clinicians managing obese or overweight young adults should be aware of the possibility of high internalising symptoms. Similarly, those managing young adults with internalising disorders should be aware of associations with lifestyle and increased BMI.

4.4. Strengths and limitations

The strengths of the present study include the use of a population-based study (Haworth et al., 2013; Rimfeld et al., 2019), the inclusion of physical and subjective health indices, a genetically sensitive design and specifying latent factors which helped overcome measurement error. Limitations include measures (including alcohol and other substance use) being self-reported which may increase recall bias. More participants with poorer physical and mental health indices did not report their BMI and were excluded from the analyses. This exclusion may mean that we underestimated differences by BMI. Although the mediation paths were guided by theory, the emergence of correlated aetiological influences as the best model suggests a greater need to focus on shared aetiological influences rather than causal processes for the studied relationships. We, therefore, recommend that future studies investigating causal processes in these relationships should adjust for shared genetic and environmental influences. Both mechanisms (i.e., causal versus shared genetic and environmental influences) may operate simultaneously (e.g., Castro-de-Araujo et al., 2023; Oginni et al., 2023) or separately at different timepoints during development (e.g., causal processes at a later timepoint than in the present study). Thus, further research is needed to determine whether these processes are consistent at different developmental timepoints and/or whether longitudinal associations reflect causality or correlated genetic and environmental. Future studies should also investigate the role of protective factors like social support (Ayed et al., 2019) which were not included in the present study and how they can ameliorate these processes. Finally, considering the small proportion of non-white participants in the present sample. Our findings may not generalise to non-white participants or other non-Western settings.

5. Conclusion

We provide evidence that although the association between internalising problems and BMI/self-rated physical health appeared to be mediated by health risk behaviours and poor sleep quality; these associations were better explained by correlated genetic and environmental influences. Furthermore, these aetiological relationships were stronger among those with high BMIs. Our findings are significant for health professionals involved in mental health care and among those who are overweight or obese and vice versa. Care must be holistic, incorporating the mental and physical healthcare needs of individuals with high BMI.

CRediT authorship contribution statement

Olakunle A. Oginni: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Geneviève Morneau-Vaillancourt:** Writing – review & editing, Conceptualization. **Alicia J. Peel:** Writing – review & editing. **Elham Assary:** Writing – review & editing, Conceptualization. **Elisavet Palaiologou:** Writing – review & editing. **Celestine Lockhart:** Writing – review & editing, Data curation. **Alice M. Gregory:** Writing – review & editing. **Helena M.S. Zavos:** Writing – review & editing. **Matthew Hotopf:** Writing – review & editing. **Thalia C. Eley:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2025.120538.

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