Associations between socioeconomic factors and depression in Sri Lanka: The role of gene-environment interplay

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Abstract

Background: Low socioeconomic status is a risk factor for depression. The nature and magnitude of associations can differ cross-culturally and is influenced by a range of contextual factors. We examined the aetiology of socioeconomic indicators and depression symptoms and investigated whether socioeconomic indicators moderate genetic and environmental influences on depression symptoms in a Sri Lankan population.

Methods: Data were from a population-based sample of twins (N = 2934) and singletons (N = 1035) in Colombo, Sri Lanka. Standard of living, educational attainment, and financial strain were used to index socioeconomic status. Depression symptoms were assessed using the Revised Beck Depression Inventory. Structural equation modelling explored genetic and environmental influences on socioeconomic indicators and depression symptoms and moderation of aetiological influences on depression symptoms by socioeconomic status.

Results: Depression symptoms were associated with lower standard of living, lower educational attainment, and financial strain. Sex differences were evident in the aetiology of standard of living, with a small contribution of genetic influences in females. Educational attainment was moderately heritable in both males and females. Total variance in depression was greater among less socioeconomically advantaged individuals. Modest evidence of moderation of the aetiology of depression by standard of living and education was observed.

Limitations: While the sample is representative of individuals living in Colombo District, it may not be representative of different regions of Sri Lanka.

Conclusions: The aetiology of depression varies across socioeconomic contexts, suggesting a potential mechanism through which socioeconomic disadvantage increases the risk for depression in Sri Lanka. Findings have implications for cross-cultural investigations of the role of socioeconomic factors in depression and for identifying targets for social interventions.

Key words: Depression; Socioeconomic status; Twin studies; Gene-environment interaction; Sri Lanka

Introduction

Major depression is highly prevalent and a leading cause of global disability (World Health Organization, 2017). The rising burden of depression worldwide disproportionately affects low- and middle-income countries (LMIC), where more than 80% of this disease burden is among people living in these countries (World Health Organization, 2017). Socioeconomic status (SES) is considered a key social determinant of depression (Maselko, 2017). In LMIC, household assets, educational attainment, and financial strain are commonly used to capture SES as these are considered most relevant to the processes of social stratification (Howe et al., 2012). Using these indicators, epidemiological studies in LMIC have shown that lower SES is associated with increased rates of depression (Lund and Cois, 2018; Maselko et al., 2017). However, although the greatest health disparities are observed in LMIC, little research has been conducted in these setting, instead it is focused on high-income countries (Polderman et al., 2015; Saxena et al., 2006). Reducing this burden requires a better understanding of the causal relationships underlying the observed association between socioeconomically disadvantaged circumstances and depression.

Two principal pathways are thought to underlie the observed associations between SES and mental health outcomes; social causation and social selection (Dohrenwend et al., 1992). The social causation hypothesis posits that exposure to the adverse social and economic conditions associated with lower SES (such as poor environmental conditions, material and social deprivation, and increased exposure to adverse and stressful life events) increases the risk for mental health conditions. The social selection hypothesis suggests that individuals with mental health disorders are more likely to drift into or remain in lower SES levels due to disability, reduced economic productivity, loss of employment, increased health expenditure, and stigma as a result of their illness. A recent longitudinal study in a nationally representative sample from South Africa found evidence for a reciprocal relationship between SES and depression, suggesting social causation and social selection act simultaneously to reinforce cycles of socioeconomic disadvantage and depression (Lund and Cois, 2018).

Associations between socioeconomic factors and depression could also arise because they share common causes. Genetic influences have been shown to be associated with environmental exposures (Kendler and Baker, 2007). This is known as gene-environment correlation (rGE) and describes genetically influenced behaviour which can influence individuals' exposure to certain environments. Genetically informative research has provided evidence for significant genetic influence on depression (Sullivan et al., 2000) and indicators of SES (Ball et al., 2010; Hill et al., 2019; Rimfeld et al., 2018). If there is an overlap in the genetic factors associated with these traits, then part of the link between them could be explained by common genetic influences. Research has provided evidence for genetic overlap between socioeconomic indicators and depression (Hill et al., 2019), suggesting that part of the link between them could be explained by common genetic influences. These findings could be taken as support for the social selection hypothesis, in which affected individuals may be more likely to drift into or remain at lower SES levels, at least in part, based on genetically influenced traits and behaviours related to depression.

Socioeconomic conditions may also affect the relative importance of genetic and environmental influences on depression within a population. This is known as gene-environment interaction (GxE) and reflects a form of social causation whereby aetiological influences on a trait are moderated by context (Rutter et al., 2006). One study investigating GxE in depression in twins in the United States found non-shared environmental influences on internalising symptoms to be greater at lower levels of income (South and Krueger, 2011). This suggests that in environments with greater adversity, genetic effects on depression may be masked. This would lead to genetic effects being more clearly detected in enriched environment. In the context of HIC and LMIC, this would suggest that genetic effects would be easier to detect in HIC compared to LMIC. However, in another study, based in the United States, higher levels neighbourhood socioeconomic disadvantage were associated with greater genetic influences (Strachan et al., 2017). To date, genetically informative research has been largely restricted to high-income populations (Polderman et al., 2015). Bias towards Western populations is problematic because estimates of genetic and environmental sources of individual differences are specific to a population at a particular time. Studies conducted in different countries show modest evidence of differences in aetiology of depression, however, to date there has been no study which directly addresses cross-country variability by comparing different heritability estimates across multiple cohorts in different countries (Ball et al., 2009; Hur, 2008; Sullivan et al., 2000; Zavos et al., 2020).

Given the increased levels of socioeconomic disadvantage and disease burden in LMIC, further exploration is needed to understand individual differences in socioeconomic variables and their influence on depression. In a population-based sample of Sri Lankan twins and singletons, we investigated (1) associations between socioeconomic indicators and depression symptoms; (2) the role of gene-environment correlation (rGE) in indicators of SES, if significant genetic influences on SES are observed, then this could reflect a form of social selection; and (3) whether socioeconomic indicators moderate the genetic and environmental influences on depression symptoms (GxE). If a significant interaction between socio-economic indicators and genetic influences on depression are observed, then this could reflect a form of social causation whereby certain socioeconomic contexts moderate aetiological influences on susceptibility to depression.

Methods

Sample

The Colombo Twin and Singleton Study (CoTASS) is a population-based study that took place between 2005-2007 in Colombo, Sri Lanka, including 4,009 twins (of which 1,954 were identified as complete twin pairs) and 2,019 singletons (Siribaddana et al., 2008). The initial participation rate was 91% among eligible twins and 87% among singletons. This study uses data from COTASS-2, a follow-up study conducted between 2012-2015. In COTASS-2, questionnaire data was available from 3934 twins (*N* = 2899) and singletons (*N* = 1035), comprising 76.4% of the original COTASS-1 sample (Jayaweera et al., 2018). The sample were 57.6% female, and the mean age was 42.8 years. Written informed consent was obtained from all participants. Participants were offered 750 LKR (approximately £3.50) upon completion of one or more study components to compensate for time and inconvenience. Full details of the COTASS-2 study are described in Jayaweera et al. (2018). The study received ethical approval from the Faculty of Medical Sciences University of Sri Jayewardenepura Ethical Review Committee (USJP ERC; reference number: 596/11) and from the Psychiatric, Nursing and Midwifery Research Ethics Subcommittee, King's College London, UK (reference number: PNM/10/11-124).

Interview measures

Questionnaire data were collected by trained field research assistants. Interviews lasted 1-2 hours and were typically conducted in participants' homes. Questionnaires were translated into Sinhalese by a panel of health professionals fluent in both Sinhala and English. Translations were cross-culturally adapted in wording to best describe questionnaires in their meaning (Sumathipala and Murray, 2000).

Socioeconomic status (SES) indicators

Standard of living. Questionnaire items relating to housing conditions, ownership of household appliances and access to transport were used to index standard of living (see Supplementary Table S1). Composite standard of living scores were created by taking the sum of the items. Scores ranged between 1 to 17, with higher values indexing higher standard of living.

Educational attainment. Participants were asked to report their level of educational attainment. Response values ranged from 0 (*no education*) to 6 (*university or higher*).

Financial strain. To measure financial strain, participants were asked "how well do you feel you are managing financially these days?". Response options were based on a five-point scale ranging from "finding it very difficult to make ends meet" to "living comfortably".

Depression symptoms

The Revised Beck Depression Inventory (BDI-II) was used to measure depression symptoms and severity in the past two weeks (Beck et al., 1996). The BDI-II is a self-report questionnaire consisting of 21 items. For each item, four response options arranged in increasing severity are presented on a 4-point scale (0-3). Item-level scores were summed to create a composite score. Higher total scores indicated greater severity of depression symptoms. The BDI-II is a reliable measure of depression and has been previously validated in the Sri Lankan population (Rodrigo et al., 2015).

Zygosity

Zygosity was ascertained in CoTASS-1 using a self-report questionnaire measure of similarity (Siribaddana et al., 2008). If zygosity was missing in CoTASS-1, it was replaced with zygosity information collected using the same measure in CoTASS-2 (n = 88). Zygosity characteristics are in line with the usual distribution seen in population studies, with slightly more MZ versus DZ twin pairs, and opposite sex pairs being the largest group (Jayaweera et al., 2018).

Statistical analysis

We conducted a series of analyses to obtain the following estimates: (1) associations between SES indicators and depression symptoms; (2) estimates from univariate twin analyses; (3) estimates from biometric bivariate moderation (GxE) analyses. All analyses were conducted in R v.4.0.2 (https://www.R-project.org/; R Core Team, 2020).

Phenotypic associations

Linear regression analyses were performed to assess phenotypic associations between sociodemographic variables, SES indicators, and depression symptoms. Analyses were clustered using the 'lm.cluster' function in the 'miceadds' package (https://CRAN.R-project.org/package=miceadds) (Robitzsh and Grund, 2021) which returns clustered standard errors to account for the non-independence of twins in the sample.

Twin model fitting

Twin design

The twin design compares intra-class correlations of identical (monozygotic, MZ) and non-identical (dizygotic, DZ) twin pairs to estimate the contribution of genetic and environmental factors to observed phenotypic variance in a trait and/or covariance between traits (Rijsdijk and Sham, 2002). The classical twin method is based on the following assumptions: (1) MZ twins share 100% of their genes and DZ twins share on average 50% of their segregating genes (i.e., genes that differ between individuals); (2) MZ and DZ twin pairs share environmental influences common to both twins in the same family to the same extent (‘shared environment’); and (3) MZ and DZ twin pairs differ from one another due to exposure to environmental factors which are unique to the individual (‘non-shared environment’). The twin model attributes the similarity of reared-together twins to additive genetic (A) factors and shared environmental (C) factors that are common to both twins in the same family. The correlation between twins’ shared environment is assumed to be 1 for both MZ and DZ pairs. The differences between MZ and DZ twin pairs is attributed to non-shared environmental influences (E) which are unique to the individual. By comparing differences in correlations between MZ and DZ twin pairs and linking these back to the model of the expected correlations (A+C for MZ pairs and 0.5A+C for DZ pairs), it is possible to establish the role of genetic and environmental influences. If MZ twins are more correlated on a trait than DZ twins, then genetic influences are assumed. Shared environmental influences are assumed if the DZ twin correlation is greater than half of MZ twin pairs. The extent to which MZ twins differ on a trait indicates non-shared environmental influences and measurement error.

Univariate ACE models

Structural equation model-fitting analyses were performed to estimate the relative contribution of additive genetic (A), shared environment (C), and non-shared environment (E) factors to the variation in SES indicators and depression symptoms. First, a heterogeneity ACE model was fit to the data in which the A, C and E parameters are estimated separately for males and females allowing for quantitative sex differences. To test for variance differences between males and females, a scalar effects model was then performed, which allows only phenotypic variance differences between males and females but equates A, C and E in males and females. Last, a homogeneity model was fitted, in which scalar effects were dropped and all parameters were held equal for males and females. The relative fit of models allowing for different types of sex differences (i.e., quantitative and variance differences between the sexes) and no sex differences were compared to assess which model best describes the data.

Biometric moderation (GxE) models

Bivariate biometric moderation models (Purcell, 2002) were used to investigate whether SES indicators moderate the aetiology of depression. Modelling of biometric moderation in a structural equation framework allows for different ACE estimates for subgroups in the population with a certain standing on a moderator variable (Purcell, 2002; van der Sluis et al., 2012) (Figure 1). This model is an extension of a bivariate decomposition in which the variance in two variables, and the covariance between them, is partitioned into genetic, shared environmental and non-shared environmental effects. In the moderation model, the moderation effects are modelled directly on the path loadings of the ACE variance components unique to the trait, as well as the variance components shared between the trait and moderator (Figure 1). As such, it is possible to simultaneously model: (1) shared genetic and environmental effects between the moderator and trait, (2) the moderation of the genetic and environmental variance components shared between the moderator and trait, and (3) the moderation of the variance components unique to the trait. To test for the significance of moderation, we compared each full moderation model with a no-moderation model, in which all moderation parameters were dropped (β_{ac}, β_{cc}, β_{ec}, β_{au}, β_{cu} and β_{eu} constrained to zero). We then tested whether moderation on the individual ACE variance components was significant by examining the 95% confidence intervals (CI) around the moderated parameters from the full model. We did not fit constrained sub models to test for the significance of individual moderated parameters because omission of moderation effects by fixing them to 0 can bias estimation of parameters (e.g., dropping ßc can inflate ßa, and there are issues of specificity in distinguishing between ßa and ßc) (Van Hulle and Rathouz, 2015).

All SEM analyses were conducted using the open-source package OpenMx (Neale et al., 2016). OpenMx uses full-information maximum-likelihood to estimate model parameters. Study variables were age (in years) and sex corrected prior to model fitting and standardised residuals were used. The residual score for depression symptoms was log transformed to reduce positive skew. Models were fitted using full-information maximum-likelihood estimation and compared using likelihood ratio testing (differences in -2 Log-likelihood and associated degrees of freedom, which is x^2 distributed) and the Akaike's Information Criterion (AIC) (Akaike, 1987).

Results

1. Associations between SES indicators, sociodemographic characteristics and depression symptoms

Adjusted associations between sociodemographic variables and SES indicators are shown in Table 1 (see Supplementary Table S2 for unadjusted β coefficients). Females reported lower levels of standard of living and financial strain compared to males. Those who had been previously married reported lower educational attainment compared to married individuals. Living in non-urban areas was associated with lower standard of living and higher financial strain. The indicators of SES were associated with one another (Supplementary Table S2), and associations remained significant after adjustment for other sociodemographic factors (Table 1).

The mean score of BDI-II depression symptoms reported in the current sample was 4.86. Higher depression scores were observed in females compared to males (β = 1.48, 95% CI [1.08, 1.88]). Higher depression scores were significantly associated with lower standard of living, lower educational attainment, and financial strain (Table S3). These associations remained significant after adjusting for sex and age (Table S3).

2. Univariate ACE model fitting

Twin correlations and ACE parameter estimates from the best-fitting models are presented in Table 2. Fit statistics from the univariate ACE model-fitting analyses are shown in Supplementary Table S4. Significant genetic influences were observed for standard of living in females, and for educational attainment in both males and females. Moderate shared and non-shared environmental influences were also apparent for both standard of living and educational attainment. Twin correlations for financial strain were higher in male DZs compared to MZs and the univariate ACE model did not fit the data, suggesting that this variable will not conform to any genetic model. We therefore did not pursue further biometric model fitting with this variable. Variance in depression was explained by genetic and non-shared environmental influences.

3. Biometric moderation (GxE) model fitting

Bivariate biometric moderation models were applied to test whether the aetiology of depression symptoms was moderated by (1) standard of living or (2) educational attainment. Scalar sex differences for depression symptoms were modelled. We did not examine whether standard of living moderated the aetiology of depression symptoms separately for males and females due to limited sample size. We observed significant moderation as a function of each SES indicator (Table S5), however, could not determine whether this was due to genetic or environmental moderation. Moderated parameter estimates derived from each of the full moderation models are shown in Table 3.

3.1. Depression symptoms moderated by standard of living

Figure 2a shows the unstandardised variance in depression symptoms moderated by standard of living. Lower standard of living was associated with greater variance in depression symptoms compared to higher levels of standard of living. Dropping moderation parameters resulted in a significant decrease in fit compared to the full moderation model (Table S5). Figure 2a suggests that genetic influences unique to depression symptoms increased with higher standard of living. Shared and non-shared environmental influences unique to depression were greater at lower standard of living. However, no single variance component appeared significantly moderated by standard of living when confidence intervals around the moderation terms were inspected (Table 3).

3.2. Depression symptoms moderated by educational attainment

Figure 2b shows the unstandardised variance in depression symptoms moderated by educational attainment. Total variance in depression symptoms was greater at lower levels of educational attainment. Dropping all moderation parameters resulted in a significant decrease in fit compared to the full moderation model (Table S5). Figure 2b suggests that genetic influences unique to depression symptoms were lower at high, compared to low levels of educational attainment. Environmental influences unique to depression symptoms do not appear to vary greatly as a function of educational attainment. However, this should be considered indicative as confidence intervals indicated that no individual variance component was significantly moderated by educational attainment (Table 3).

3.3. Post-hoc analyses

Post-hoc model fitting analyses were performed to assess the moderating effects of SES indicators on (1) the ACE variance components shared between depression and each SES indicator (β_{ac}, β_{cc} and β_{ec} constrained to zero), and (2) the variance components unique to depression symptoms (β_{au}, β_{cu} and β_{eu} constrained to zero). Results showed that the moderated ACE variance components unique to depression symptoms could not be dropped without a significant worsening of fit to the data compared with the full moderation models (Table S5). This suggests presence of moderation on the variance components unique to depression and is consistent with the moderation effects observed in Figure 2. No individual variance component appeared significantly moderated by standard of living or educational attainment when confidence intervals around the moderation terms were inspected. Further, post-hoc *phenotypic* moderation model fitting analyses were performed to assess the moderating effects of SES indicators on (1) the phenotypic variance shared between depression and each SES indicator (Bc constrained to zero), and (2) the phenotypic variance unique to depression symptoms (Bu constrained to zero). This allowed us to estimate one overall Beta-c (with 95% CI) and one overall Beta-u (with 95% CI). Results showed that the moderated variance unique to depression symptoms could not be dropped without a significant worsening of fit to the data compared with the full moderation models (Table S6). Examination of the confidence intervals around the moderation parameter estimates from the full model showed significant moderation of the variance unique to depression symptoms (Bu = -0.04, 95% CI [-0.06, -0.02]). This suggests presence of moderation on the overall variance unique to depression and is consistent with the moderation effects observed in Figure 2. Post-hoc bivariate analyses were also conducted to assess genetic and environmental correlations between each SES indicator and depression symptoms. Significant genetic correlations between depression symptoms and both standard of living and educational attainment were observed (Table S7).

Discussion

The current study sought to examine the relationship between socioeconomic factors and depression symptoms using genetically informative data from a population-based sample of twins and singletons in Sri Lanka. In line with previous findings (Maselko et al., 2017), we found moderate phenotypic associations between the different socioeconomic indicators. Lower standard of living, poor educational attainment and financial strain were independently associated with higher depression symptoms, consistent with previous research indicating that individuals with lower SES are at increased risk for depression (Lund and Cois, 2018; Maselko, 2017; Maselko et al., 2017). Results provide support for both social selection (significant genetic influences on SES indicators) and preliminary support for social causation (GxE).

Sex differences were identified in the aetiology of standard of living, with evidence of a small contribution of genetic influences on standard of living in females but not in males. Genetic influences on standard of living in females may be accounted for lower variation in environmental exposures due to cultural gender limitations. For example, the majority of working age females in Sri Lanka are not in salary-based employment (~73%) and economically inactive (Department of Census and Statistics Sri Lanka, 2019). The main reason reported is caregiver, family work and housework activities (Department of Census and Statistics Sri Lanka, 2019). Environmental influences explained the majority of variance for standard of living. Our results are broadly in line with previous research using an earlier wave of the COTASS sample (Ball et al., 2010). Our finding that 44-63% of the variance in standard of living was due to environmental factors shared within the family (C) contrast with reports of relatively small or zero shared environmental effects on socioeconomic indicators in studies from adults in HIC (Rimfeld et al., 2018). This could be explained by differences in socio-cultural norms such as higher prevalence of extended, multigenerational, family households and greater importance given to family-based networks in LMIC (Maselko, 2017). Larger environmental variation in standard of living could also indicate less equal access or opportunity in employment sectors in Sri Lanka compared to in countries where higher heritability estimates for socioeconomic factors have been reported (Rimfeld et al., 2018). Informal employment is estimated to account for 66.7% of total employment in Sri Lanka compared to 18% in HIC (Bonnet et al., 2019; Department of Census and Statistics Sri Lanka, 2019). Those who are employed in the informal economy face multiple challenges, such as low job security and difficult working conditions, and informal work is often undertaken due to absence of other means of livelihood (Bonnet et al., 2019). Given that traits and behaviours related to SES are substantially genetic in origin, greater equality of opportunity means that environmental inequalities have less impact on outcomes. Individual differences in socioeconomic factors that remain after systemic environmental inequalities are reduced are to a greater extent due to genetic differences.

Educational attainment was moderately heritable with a significant contribution of shared and non-shared environmental influences in males and females. Heritability of educational attainment in both sexes may be indicative of gene-environment correlation. Higher heritability for educational attainment could reflect that the education system is more meritocratic in Sri Lanka than other aspects of the socioeconomic context (Rimfeld et al., 2018). Primary and secondary education in Sri Lanka is free and enrolment in secondary education is 91% for both genders (UNESCO Institute for Statistics, 2018). This is consistent with research demonstrating higher heritability for educational attainment in societies with greater equality in educational opportunities (Rimfeld et al., 2018).

We found evidence that SES indicators moderated the aetiology of depression. However, we did not find significant moderation of the individual ACE variance components unique to depression, contrary to prior work (South and Krueger, 2011; Strachan et al., 2017). Our most consistent finding was that total variance in depression symptoms was greater among lower-SES individuals, which was driven by greater genetic and environmental variance components unique to depression at lower levels of SES, without the ability to detect moderation of each component individually as significant. This is partially consistent with findings from previous GxE studies (South and Krueger, 2011; Strachan et al., 2017) and provides evidence that is consistent with the notion that social causation processes play a role in the observed association between depression and SES across different populations (Dohrenwend et al., 1992; Lund and Cois, 2018; South and Krueger, 2011). Our results also showed that the shared variance components between socioeconomic indicators and depression symptoms were zero across the entire SES distribution. This suggests that socioeconomic factors may have a main effect on the aetiology of depression independently of shared aetiological influences.

Strengths and limitations

A strength of our study is the use of a large representative population-based twin and singleton sample based in Sri Lanka, especially given the limited availability of genetically informative data in LMIC populations (Polderman et al., 2015). We used different socioeconomic indicators intended to capture different aspects of the socioeconomic context. Thus, we were able to examine and compare individual differences in socioeconomic outcomes and their role in the aetiology of depression symptoms. In addition, the wide availability of asset index data and educational attainment in many studies and comparable data across multiple countries is an important strength because it facilitates comparative research. Some limitations should be considered. First, self-reported socioeconomic factors and depression symptoms could be underreported due to the sensitive and/or private nature and stigma associated with reporting them (Lorant et al., 2007). Second, we did not investigate whether the pattern of moderating effects by socioeconomic conditions vary over age. Differences in moderation could be expected given that the aetiology of mental health problems changes across development (Hannigan et al., 2017). Future studies could seek to explore how the dynamics of different socioeconomic conditions relate to aetiologic moderation on depression symptoms across age. Third, while the sample is representative of individuals living in Colombo District, it may not be representative of different regions of Sri Lanka. Lastly, the twin method rests on certain assumptions that when unmet may challenge the validity of the results (Rijsdijk and Sham, 2002).

Conclusion

The present study extends our understanding of the relationship between socioeconomic factors and depression symptoms using data from a representative twin and singleton population study based in Colombo, Sri Lanka. Shared and non-shared environmental influences accounted for the majority of variance in standard of living, whereas educational attainment showed moderate heritability. Socioeconomic indicators moderated the variance unique to depression symptoms, consistent with previous investigations in samples drawn from different social, economic, and cultural contexts. However, we were unable to determine whether this was due to genetic or environmental moderation. This is the first study to use bivariate moderation modelling to investigate whether socioeconomic factors moderate aetiological influences on depression symptoms in a South Asian population. This study has implications for future cross-cultural investigations of the mechanisms underlying associations between socioeconomic factors and depression symptoms and has the potential to inform intervention strategies to reduce social disparities in depression.

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Table 1. Associations between socioeconomic status indicators and sociodemographic characteristics.

	N	Standard of living Adjusted β	Educational attainment Adjusted β	Financial strain Adjusted β
Sex				
Male (ref)	1681 (42.4%)			
Female	2288 (57.6%)	-0.10 (-0.15, -0.04)**	0.11 (0.06, 0.17)**	-0.07 (-0.13, -0.01)*
Age				
19-29 (ref)	853 (21.5%)			
30-39	1012 (25.5%)	0.00 (-0.09, -0.10)	-0.26 (-0.35, -0.17)**	-0.02 (-0.11, 0.08)
40-49	825 (20.8%)	0.15 (0.05, 0.25)**	-0.42 (-0.51, -0.32)**	-0.14 (-0.25, -0.03)*
50-59	665 (16.8%)	0.23 (0.12, 0.34)**	-0.53 (-0.63, -0.43)**	-0.07 (-0.18, 0.04)
60-69	376 (9.5%)	0.22 (0.10, 0.35)**	-0.59 (-0.71, -0.48)**	-0.12 (-0.26, 0.01)
>70	203 (5.1%)	0.22 (0.04, 0.40)*	-0.63 (-0.79, -0.47)**	0.13 (-0.04, 0.31)
Ethnicity				
Sinhala (ref)	3647 (91.9%)			
Tamil	120 (3.0%)	-0.22 (-0.44, -0.00)	-0.24 (-0.44, -0.04)*	-0.02 (-0.23, 0.19)
Muslim	150 (3.8%)	0.26 (0.11, 0.40)**	-0.49 (-0.61, -0.36)**	0.01 (-0.13, 0.15)
Other Minority	16 (0.4%)	0.38 (0.15, 0.61)**	-0.16 (-0.56, 0.24)	-0.41 (-0.91, 0.09)
Marital Status				
Married (ref)	2838 (71.5%)			
Previously Married	329 (8.3%)	-0.05 (-0.17, 0.06)	-0.21 (-0.32, -0.11)**	-0.09 (-0.22, 0.05)
Never Married	763 (19.2%)	-0.01 (-0.10, 0.09)	0.17 (0.08, 0.25)**	0.01 (-0.09, 0.10)
Urbanicity				
Urban (ref)	2390 (60.2%)			
Rural	532 (13.4%)	-0.29 (-0.38, -0.21)**	-0.02 (-0.12, 0.07)	0.31 (0.23, 0.39)**
Mixed	826 (20.8%)	-0.15 (-0.22, -0.08)**	-0.11 (-0.18, -0.04)**	0.22 (0.14, 0.29)**

Outside Colombo	221 (5.6%)	-0.21 (-0.33, -0.10)**	0.17 (0.05, 0.29)**	-0.03 (-0.17, 0.11)
Standard of Living				
Mean (SD)	14.1 (2.64)	-	0.15 (0.14, 0.16)**	0.12 (0.11, 0.14)**
Educational attainment				
No education (ref)	47 (1.2%)		-	
Grade 1-5	274 (6.9%)	0.10 (-0.31, 0.51)	-	-0.22 (-0.59, 0.16)
Grade 6 0/Ls	1757 (44.3%)	0.47 (0.07, 0.86)*	-	0.02 (-0.33, 0.36)
Passed O/Ls	632 (15.9%)	0.91 (0.51, 1.31)**	-	0.25 (-0.10, 0.61)
Up to/ passed A/Ls	929 (23.4%)	1.19 (0.79, 1.59)**	-	0.29 (-0.06, 0.64)
University /higher	276 (7.0%)	1.51 (1.10, 1.91)**	-	0.30 (-0.07, 0.66)
Financial Strain				-
Very difficult to make ends meet (ref)	121 (3.0%)			-
Difficult to make ends meet	284 (7.2%)	0.50 (0.25, 0.76)**	0.01 (-0.15, 0.18)	-
Just about getting by	547 (13.8%)	0.62 (0.37, 0.87)**	0.05 (-0.11, 0.21)	-
Doing alright	2616 (65.9%)	1.01 (0.77, 1.24)**	0.24 (0.08, 0.39)	-
Living comfortably	365 (9.2%)	1.45 (1.20, 1.70)**	0.54 (0.36, 0.72)**	-

Note. Linear regressions were conducted using standardised outcome variables and clustered standard errors to account for non-independence of twins in the sample. Adjusted β coefficients were calculated after including all other socio-demographic variables in the table. *$p < 0.05$; **$p < 0.01$

Table 2. Twin correlations and univariate ACE estimates for standard of living, educational attainment, financial strain, and depression.

	Standard of living	Educational attainment	Financial strain	Depression
MZM	0.65 (0.58, 0.71)	0.68 (0.61, 0.73)	0.38 (0.25, 0.48)	0.28 (0.13, 0.40)
DZM	0.67 (0.57, 0.74)	0.58 (0.47, 0.67)	0.69 (0.59, 0.75)	0.23 (0.07, 0.37)
MZF	0.63 (0.57, 0.68)	0.74 (0.70, 0.78)	0.50 (0.42, 0.57)	0.36 (0.26, 0.46)
DZF	0.56 (0.46, 0.63)	0.54 (0.45, 0.62)	0.40 (0.29, 0.50)	0.21 (0.07, 0.34)
DZOS	0.50 (0.41, 0.57)	0.47 (0.39, 0.54)	0.39 (0.28, 0.48)	0.12 (0.01, 0.22)

	A	C	E
Standard of living			
Male	0.03 (0.00, 0.10)	0.63 (0.55, 0.70)	0.34 (0.29, 0.40)
Female	0.18 (0.03, 0.36)	0.46 (0.29, 0.59)	0.37 (0.32, 0.43)
Educational attainment	0.40 (0.28, 0.52)	0.32 (0.20, 0.42)	0.28 (0.25, 0.32)
Depression	0.32 (0.13, 0.40)	0.01 (0.00, 0.18)	0.67 (0.60, 0.76)

Note. MZM = monozygotic male, DZM = dizygotic male, MZF = monozygotic female, DZF = dizygotic female, DZOS = dizygotic opposite sex. A = additive genetic, C = shared environmental, and E = non-shared environmental influences.

Table 3. Genetic and environmental parameter estimates for depression moderated by standard of living and educational attainment.

	Standard of living	Educational attainment
Parameter		
βau	0.01 (-0.05, 0.06)	-0.04 (-0.09, 0.01)
βac	-0.01 (-0.10, 0.07)	-0.02 (-0.08, 0.05)
βcu	-0.15 (-0.23, 0.23)	0.09 (-0.20, 0.20)
βcc	0.00 (-0.06, 0.06)	-0.02 (-0.09, 0.05)
βeu	-0.04 (-0.08, 0.00)	-0.02 (-0.06, 0.01)
βec	0.02 (-0.02, 0.06)	0.04 (0.00, 0.09)

Note. Parameter estimates are derived from the full moderation (GxE) model. βau, βcu, and βeu are the moderated genetic, shared environmental, and non-shared environmental path coefficients unique to depression symptoms. βac, βcc, and βec are the moderated genetic, shared environmental, and non-shared environmental path coefficients common to the moderator (i.e., standard of living or educational attainment) and depression symptoms.

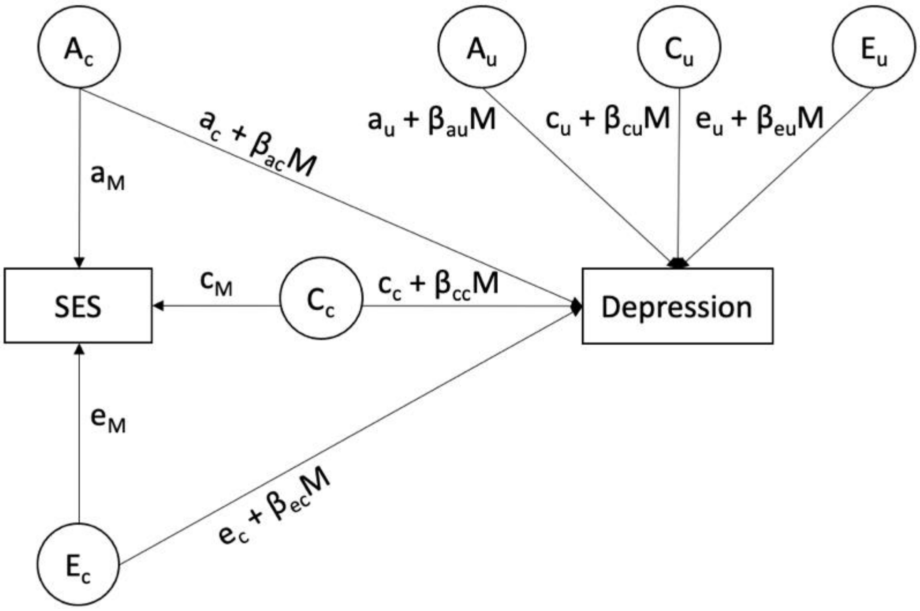

Figure 1. Bivariate moderation model shown for only one member of a twin pair as proposed by Purcell (2002). Ac, Cc and Ec are the variance components common to the moderator and the trait. Au, Cu, and Eu are the variance components unique to the trait. Path loadings for the moderator are denoted by a_M, c_M, and e_M. The cross-paths connecting the moderator to the trait consist of loadings that are unrelated to the moderator: a_c, c_c, and e_c, and cross-loadings that depend on the moderator via weights: β_{ac}, β_{cc}, and β_{ec}. The path loadings unique to the trait consist of elements unrelated to the moderator a_u, c_u, and e_u, and elements that depend on the moderator via weights β_{au}, β_{cu}, and β_{eu}. β coefficients index the direction and magnitude of moderation. The total variance of the trait can be calculated as follows: $Var(T|M) = (a_c + \beta_{ac}M)^2 + (a_u + \beta_{au}M)^2 + (c_c + \beta_{cc}M)^2 + (c_u + \beta_{cu}M)^2 + (e_c + \beta_{ec}M)^2 + (e_u + \beta_{eu}M)^2$.

(a)

(b)

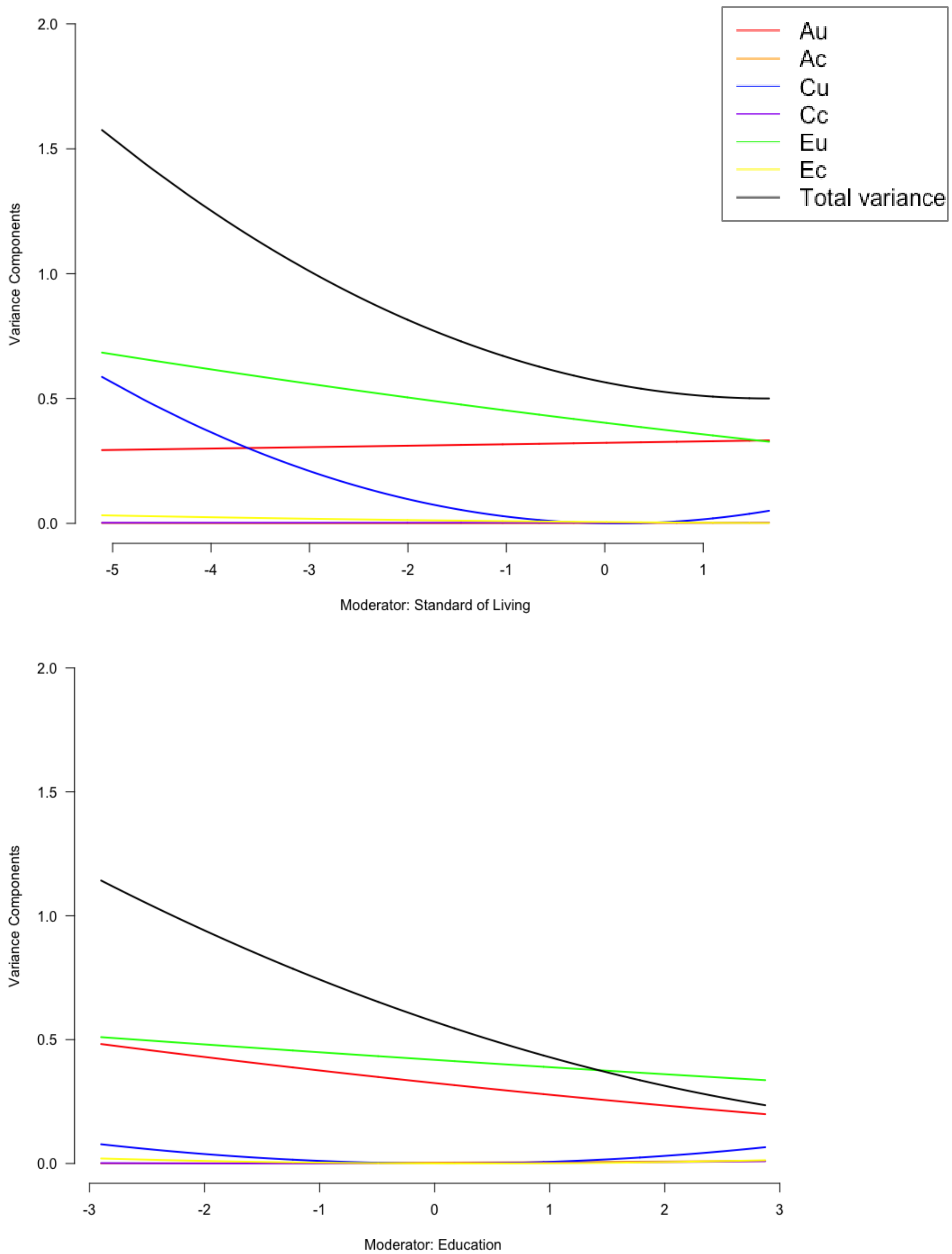

Figure 2. Variance in depression symptoms moderated by standard of living (a) and educational attainment (b). Au, Cu, and Eu are the genetic, shared environmental, and non-shared environmental variance components unique to depression. Ac, Cc and Ec are the are the genetic, shared environmental, and non-shared environmental variance components common to the socioeconomic moderator and depression.