**Supplementary material**

**Childhood anxious/withdrawn behaviour and later anxiety disorder: a network outcome analysis of a population cohort**

Monk, McLeod, Mulder, Spittlehouse, & Boden (2021)

**EBIC-gLASSO Gaussian graphical model estimation**

As implemented in *qgraph*, the graphical LASSO (gLASSO) algorithm estimates a range of models with different *λ* (lambda) values, producing a range of models with varying (logarithmically spaced) sparsity. In the present study, model selection was performed by minimising the Extended Bayesian Information Criterion (EBIC; Foygel & Drton, 2010). The EBIC is tuned with the hyperparameter *γ* (gamma), which can be manually set to any value between 0 and 1. The *γ* value controls the degree to which EBIC prefers sparser models; increasing the value of *γ* increases the preference of the EBIC for sparsity (at *γ* = 0, the EBIC reverts to the regular BIC). Subsequently, many exploratory researchers opt for a *γ* value between 0 and 0.5 to maximise the estimated connections in the model. For the present study, *γ* = 0.5 was chosen to err on the side of caution.

In the case of model estimation from skewed ordinal data, both polychoric and Spearman correlations have been frequently used as Gaussian graphical model (GGM) input. One recent simulation study (Isvoranu & Epskamp, 2021) suggests that there is little difference between the two input types when data have similar conditions to those in our study (skewed ordinal distributions with a low [n<2,500] sample size). However, Isvoranu and Epskamp (2021, pp. 25-26) do suggest that polychoric correlations offer increased sensitivity in detecting large true edges, at the implied expense of some precision: “…there was a clear inverse relationship between the sensitivity (top 25%) and precision, indicating that edges discovered by these methods are also more likely to be false edges than edges discovered by other methods.” We subsequently ran all the models in present study using both Spearman and polychoric correlations to check for indication of this. We briefly report the results of this analysis below. Models are labelled M1-M6 in the order they appear in the main manuscript and figures/tables.

*Correlation type analysis*

First, the correlations between the polychoric and Spearman versions of each model (M1-M6) were *r* = .93-.96.

Second, the below table reports the non-zero predictor-outcome edges retrieved for each outcome network model (M3-M6) using both polychoric and Spearman correlation inputs.

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| Table S1. Network outcome model (M3-M6) edge weights using both correlation types as input, sorted by estimated polychoric edge weight. | | | |
| Model | Childhood item | Polychoric | Spearman |
| M3 | AW10 | 0.178 | 0.131 |
| M3 | AW3 | 0.145 | 0.069 |
| M6 | AW5 | 0.108 | 0.065 |
| M4 | AW9 | 0.091 | 0.055 |
| M4 | AW14 | 0.087 | 0.018 |
| M5 | AW6 | 0.083 | 0.045 |
| M5 | AW10 | 0.077 | 0.066 |
| M4 | AW7 | 0.069 | 0.025 |
| M3 | AW5 | 0.058 | 0.028 |
| M4 | AW4 | 0.055 | - |
| M6 | AW10 | 0.054 | 0.029 |
| M6 | AW4 | 0.051 | 0.010 |
| M5 | AW11 | 0.047 | 0.046 |
| M6 | AW12 | 0.046 | 0.020 |
| M6 | AW7 | 0.045 | 0.030 |
| M3 | AW6 | 0.041 | 0.024 |
| M5 | AW12 | 0.033 | 0.011 |
| M6 | AW2 | 0.025 | - |
| M4 | AW11 | 0.024 | - |
| M4 | AW3 | 0.012 | - |
| M3 | AW8 | 0.012 | - |
| M4 | AW15 | 0.009 | - |
| M4 | AW2 | 0.009 | - |
| M6 | AW6 | 0.002 | - |
| M3 | AW1 | - | 0.009 |
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Several aspects of this analysis are consistent with results reported by Isvoranu and Epskamp (2021). First, the two inputs produce networks with little global differences (*r* = .93-.96), and edges estimated as non-zero tended to be the same across correlation types (16/17 non-zero Spearman edges were also estimated as non-zero via polychoric correlations). Second, there is an indication that the polychoric input may result in higher-sensitivity networks: the edge weights are stronger and there are more non-zero edges. Third, there is indication that the Spearman input could result in networks with greater precision: edge weights are weaker, and the weakest seven polychoric edges were estimated as zero via Spearman input.

*Conclusions from correlation type analysis*

Isvoranu and Epskamp (2021) suggest that polychoric and Spearman correlations may offer similar approximations of true network structures under conditions similar to our data. They do, however, suggest that polychoric correlations may offer some increased sensitivity at the implied expense of some precision. Models estimated from our data produce results which are consistent with this: we see a pattern which is consistent with both polychoric correlations having greater sensitivity, and Spearman correlations having greater precision. Either, or both, of these interpretations could be true. As we do not know the true data-generating mechanism, it is impossible to say. As such, we opted to err on the side of caution and estimate our main models with Spearman correlations, which offer a more conservative estimate of the true network. This is imperative for the present research, as we are making inferences based on the presence, or lack thereof, of particular edges, and the interpretation of false positive edges (which some of the weaker polychoric edges may be) would contribute to erroneous conclusions.

**Mixed graphical model estimation**

The Mixed Graphical Model (MGM) estimation procedure allows modelling of variables with different underlying distributions in the same network. This is in contrast to other types of network models which require a uniform multivariate distribution, such as the Gaussian graphical model (normal distribution) or the Ising model (binary distribution). The MGM estimates network structures using a neighbourhood regression approach: iteratively regressing each node onto every other node using the appropriate regression method in each case (e.g., logistic regression when the dependent variable is binary; Haslbeck & Waldorp, 2020). In our study, the outcomes were coded as categorical (binary) and the childhood anxiety/withdrawal items were coded as Gaussian. For each pairwise association, a regression coefficient is obtained in each direction (i.e., regressions are run with both nodes as the dependent variable). The MGMs were penalised using gLASSO and the strength of the penalty was selected using cross-validation with *k* = 5 folds. As operationalised in the *mgm* package, researchers can choose to select a non-zero parameter if *both* regression coefficients are non-zero (the “AND” rule), or if *either* of the regression coefficients are non-zero (the “OR” rule). In the present study, edges were selected via the “OR” rule.

**Network outcome analysis – rationale for estimating GGMs and MGMs**

In the case of data with a mix of ordinal or continuous items and binary items, MGMs are typically used (e.g., Fried et al., 2019; Weilenmann et al., 2021). However, estimating MGMs assumes that Gaussian-coded variables follow a Gaussian distribution. In the present study, the childhood items are skewed, likely imposing some degree of assumption violation with regard to the childhood items.

For the GGM approach, there is no published research assessing the performance of Spearman GGMs when at least one variable is binary. Rank-order transformations such as Spearman correlations have only so far been validated at GGM input in the case of ordinal variables with more than two levels (Isvoranu & Epskamp, 2021). While GGMs estimated from Spearman correlations have been shown handle skewed ordinal and continuous data quite well, it is unclear how they may perform in retrieving true parameters in the case of one variable being binary. To mitigate the potential effect of assumption violation, the models were estimated via both procedures and parameters cross-checked for robustness.

**Supplementary tables and figures**

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| Table S2. Percentage (%) of study participants meeting the diagnostic criteria for at least one DSM anxiety disorder during each assessment period | | |
| Assessment period | Male | Female |
| 14–15 years | 6.7 | 18.1 |
| 15–16 years | 13.4 | 36.8 |
| 16–18 years | 11.0 | 21.7 |
| 18–21 years | 7.4 | 18.0 |
| 20–25 years | 12.7 | 24.1 |
| 25–30 years | 13.4 | 24.6 |
| 30–35 years | 14.5 | 22.3 |
| 35–40 years | 13.1 | 17.3 |
| Notes: The earliest two assessment periods (14–15 and 15–16 years) were assessed using DSM-III-R criteria for anxiety disorders; subsequent assessments all used the DSM-IV criteria. See Method section of main paper for anxiety disorders assessed. | | |

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| Table S3. Spearman correlations between childhood anxiety/withdrawal items (7–9 years) and DSM anxiety disorder at each assessment (15, 16, 18, 21, 25, 30, 35, and 40 years) for male subsample | | | | | | | | | | | | | | | | | | | | | | | |
| Variables | AW1 | AW2 | AW3 | AW4 | AW5 | AW6 | AW7 | AW8 | AW9 | AW10 | AW11 | AW12 | AW13 | AW14 | AW15 | AD15 | AD16 | AD18 | AD21 | AD25 | AD30 | AD35 | AD40 |
| AW1 | - | .37 | .23 | .02 | .10 | .28 | .43 | .37 | .23 | .23 | .29 | .28 | .27 | .41 | .44 | .10 | .05 | .12 | .13 | -.02 | .09 | .11 | .04 |
| AW2 | .37 | - | .22 | .05 | .04 | .10 | .19 | .43 | .22 | .06 | -.03 | .06 | .02 | .11 | .08 | .01 | .05 | .00 | .03 | -.03 | .09 | .09 | -.02 |
| AW3 | .23 | .22 | - | .12 | .10 | .08 | .16 | .13 | .14 | .06 | .04 | -.02 | .03 | .05 | .05 | .14 | .16 | -.01 | .11 | -.01 | .10 | .04 | .09 |
| AW4 | .02 | .05 | .12 | - | .14 | .04 | .18 | .06 | .14 | .00 | -.02 | -.05 | -.03 | -.07 | -.02 | .03 | .06 | -.03 | -.01 | .04 | .02 | -.05 | .02 |
| AW5 | .10 | .04 | .10 | .14 | - | .31 | .29 | .07 | .30 | .17 | .29 | .17 | .07 | .04 | .13 | .07 | .12 | .14 | .03 | .06 | .09 | .05 | -.01 |
| AW6 | .28 | .10 | .08 | .04 | .31 | - | .43 | .17 | .18 | .39 | .42 | .40 | .17 | .15 | .31 | .17 | .14 | .12 | .14 | .14 | .15 | .12 | .05 |
| AW7 | .43 | .19 | .16 | .18 | .29 | .43 | - | .22 | .28 | .26 | .42 | .44 | .19 | .25 | .38 | .07 | .08 | .01 | .06 | .09 | .11 | .08 | .12 |
| AW8 | .37 | .43 | .13 | .06 | .07 | .17 | .22 | - | .28 | .14 | .05 | .09 | .10 | .26 | .17 | .07 | .10 | .01 | .08 | .03 | .13 | .08 | .04 |
| AW9 | .23 | .22 | .14 | .14 | .30 | .18 | .28 | .28 | - | .25 | .07 | .09 | -.01 | .07 | .04 | .06 | .03 | .03 | .02 | .02 | -.05 | .08 | -.08 |
| AW10 | .23 | .06 | .06 | .00 | .17 | .39 | .26 | .14 | .25 | - | .24 | .34 | .12 | .23 | .22 | .13 | .15 | .15 | .15 | .16 | .10 | .14 | .08 |
| AW11 | .29 | -.03 | .04 | -.02 | .29 | .42 | .42 | .05 | .07 | .24 | - | .46 | .18 | .16 | .40 | .07 | .03 | .13 | .12 | .17 | .14 | .12 | .07 |
| AW12 | .28 | .06 | -.02 | -.05 | .17 | .40 | .44 | .09 | .09 | .34 | .46 | - | .26 | .32 | .38 | .10 | .03 | .12 | .11 | .14 | .13 | .11 | .11 |
| AW13 | .27 | .02 | .03 | -.03 | .07 | .17 | .19 | .10 | -.01 | .12 | .18 | .26 | - | .41 | .37 | .04 | .04 | .10 | -.03 | .04 | .07 | -.01 | .06 |
| AW14 | .41 | .11 | .05 | -.07 | .04 | .15 | .25 | .26 | .07 | .23 | .16 | .32 | .41 | - | .43 | .08 | -.04 | .07 | .09 | .01 | .07 | .01 | .13 |
| AW15 | .44 | .08 | .05 | -.02 | .13 | .31 | .38 | .17 | .04 | .22 | .40 | .38 | .37 | .43 | - | .06 | .12 | .07 | .11 | .09 | .09 | .06 | .05 |
| AD15 | .10 | .01 | .14 | .03 | .07 | .17 | .07 | .07 | .06 | .13 | .07 | .10 | .04 | .08 | .06 | - | .14 | .09 | .06 | .07 | .10 | .08 | .05 |
| AD16 | .05 | .05 | .16 | .06 | .12 | .14 | .08 | .10 | .03 | .15 | .03 | .03 | .04 | -.04 | .12 | .14 | - | .14 | .14 | .03 | .09 | .10 | .04 |
| AD18 | .12 | .00 | -.01 | -.03 | .14 | .12 | .01 | .01 | .03 | .15 | .13 | .12 | .10 | .07 | .07 | .09 | .14 | - | .21 | .09 | .14 | .09 | .05 |
| AD21 | .13 | .03 | .11 | -.01 | .03 | .14 | .06 | .08 | .02 | .15 | .12 | .11 | -.03 | .09 | .11 | .06 | .14 | .21 | - | .14 | .28 | .23 | .18 |
| AD25 | -.02 | -.03 | -.01 | .04 | .06 | .14 | .09 | .03 | .02 | .16 | .17 | .14 | .04 | .01 | .09 | .07 | .03 | .09 | .14 | - | .33 | .29 | .24 |
| AD30 | .09 | .09 | .10 | .02 | .09 | .15 | .11 | .13 | -.05 | .10 | .14 | .13 | .07 | .07 | .09 | .10 | .09 | .14 | .28 | .33 | - | .30 | .37 |
| AD35 | .11 | .09 | .04 | -.05 | .05 | .12 | .08 | .08 | .08 | .14 | .12 | .11 | -.01 | .01 | .06 | .08 | .10 | .09 | .23 | .29 | .30 | - | .35 |
| AD40 | .04 | -.02 | .09 | .02 | -.01 | .05 | .12 | .04 | -.08 | .08 | .07 | .11 | .06 | .13 | .05 | .05 | .04 | .05 | .18 | .24 | .37 | .35 | - |
| Notes: AW1–AW15 are childhood anxiety/withdrawal items (see Table 1 in main paper for item descriptions); AD15–AD40 are DSM anxiety disorder outcomes at each assessment. | | | | | | | | | | | | | | | | | | | | | | | |

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| Table S4. Spearman correlations between childhood anxiety/withdrawal items (7–9 years) and DSM anxiety disorder at each assessment (15, 16, 18, 21, 25, 30, 35, and 40 years) for female subsample | | | | | | | | | | | | | | | | | | | | | | | |
| Variables | AW1 | AW2 | AW3 | AW4 | AW5 | AW6 | AW7 | AW8 | AW9 | AW10 | AW11 | AW12 | AW13 | AW14 | AW15 | AD15 | AD16 | AD18 | AD21 | AD25 | AD30 | AD35 | AD40 |
| AW1 | - | .43 | .27 | .13 | .19 | .32 | .50 | .39 | .26 | .18 | .36 | .31 | .35 | .45 | .45 | .04 | .04 | .04 | .03 | -.07 | .01 | .00 | .01 |
| AW2 | .43 | - | .22 | .05 | .11 | .16 | .19 | .37 | .17 | .05 | .07 | .11 | .12 | .16 | .12 | -.01 | -.01 | .00 | -.04 | -.04 | -.03 | -.09 | -.01 |
| AW3 | .27 | .22 | - | .24 | .12 | .18 | .23 | .22 | .24 | .03 | .00 | .00 | .03 | .07 | .10 | .04 | -.02 | .06 | .01 | .00 | .07 | .07 | -.04 |
| AW4 | .13 | .05 | .24 | - | .09 | .19 | .30 | .05 | .27 | .09 | .05 | .03 | .01 | .01 | .04 | .07 | .07 | .02 | .07 | .09 | .08 | .01 | .05 |
| AW5 | .19 | .11 | .12 | .09 | - | .34 | .30 | .06 | .34 | .14 | .25 | .13 | .06 | .01 | .18 | .14 | .08 | .06 | .06 | .13 | .15 | .12 | .10 |
| AW6 | .32 | .16 | .18 | .19 | .34 | - | .48 | .18 | .25 | .28 | .36 | .43 | .15 | .12 | .30 | .15 | .01 | .05 | .13 | .05 | .11 | .08 | .10 |
| AW7 | .50 | .19 | .23 | .30 | .30 | .48 | - | .24 | .42 | .20 | .43 | .37 | .20 | .20 | .33 | .14 | .06 | .09 | .12 | .07 | .11 | .11 | .12 |
| AW8 | .39 | .37 | .22 | .05 | .06 | .18 | .24 | - | .23 | .20 | .13 | .15 | .17 | .26 | .18 | -.01 | .07 | .00 | .02 | -.04 | -.02 | .02 | .12 |
| AW9 | .26 | .17 | .24 | .27 | .34 | .25 | .42 | .23 | - | .17 | .12 | .05 | -.01 | .03 | .10 | .16 | .12 | .11 | .04 | .11 | .08 | .06 | .04 |
| AW10 | .18 | .05 | .03 | .09 | .14 | .28 | .20 | .20 | .17 | - | .13 | .27 | .14 | .22 | .19 | .02 | -.02 | .01 | .06 | .02 | .12 | .05 | .12 |
| AW11 | .36 | .07 | .00 | .05 | .25 | .36 | .43 | .13 | .12 | .13 | - | .53 | .20 | .28 | .46 | .04 | .08 | .03 | .08 | .01 | .05 | .10 | .13 |
| AW12 | .31 | .11 | .00 | .03 | .13 | .43 | .37 | .15 | .05 | .27 | .53 | - | .28 | .39 | .44 | .04 | -.05 | .07 | .18 | .02 | .06 | .12 | .18 |
| AW13 | .35 | .12 | .03 | .01 | .06 | .15 | .20 | .17 | -.01 | .14 | .20 | .28 | - | .49 | .39 | .03 | -.04 | .09 | .06 | -.02 | .01 | -.03 | .04 |
| AW14 | .45 | .16 | .07 | .01 | .01 | .12 | .20 | .26 | .03 | .22 | .28 | .39 | .49 | - | .52 | -.07 | -.08 | -.02 | .05 | -.05 | -.02 | -.01 | .08 |
| AW15 | .45 | .12 | .10 | .04 | .18 | .30 | .33 | .18 | .10 | .19 | .46 | .44 | .39 | .52 | - | -.02 | -.08 | .03 | .10 | .01 | .01 | .01 | .10 |
| AD15 | .04 | -.01 | .04 | .07 | .14 | .15 | .14 | -.01 | .16 | .02 | .04 | .04 | .03 | -.07 | -.02 | - | .38 | .33 | .22 | .14 | .16 | .13 | .13 |
| AD16 | .04 | -.01 | -.02 | .07 | .08 | .01 | .06 | .07 | .12 | -.02 | .08 | -.05 | -.04 | -.08 | -.08 | .38 | - | .31 | .20 | .27 | .06 | .16 | .15 |
| AD18 | .04 | .00 | .06 | .02 | .06 | .05 | .09 | .00 | .11 | .01 | .03 | .07 | .09 | -.02 | .03 | .33 | .31 | - | .30 | .17 | .17 | .31 | .15 |
| AD21 | .03 | -.04 | .01 | .07 | .06 | .13 | .12 | .02 | .04 | .06 | .08 | .18 | .06 | .05 | .10 | .22 | .20 | .30 | - | .30 | .27 | .27 | .29 |
| AD25 | -.07 | -.04 | .00 | .09 | .13 | .05 | .07 | -.04 | .11 | .02 | .01 | .02 | -.02 | -.05 | .01 | .14 | .27 | .17 | .30 | - | .29 | .21 | .26 |
| AD30 | .01 | -.03 | .07 | .08 | .15 | .11 | .11 | -.02 | .08 | .12 | .05 | .06 | .01 | -.02 | .01 | .16 | .06 | .17 | .27 | .29 | - | .35 | .22 |
| AD35 | .00 | -.09 | .07 | .01 | .12 | .08 | .11 | .02 | .06 | .05 | .10 | .12 | -.03 | -.01 | .01 | .13 | .16 | .31 | .27 | .21 | .35 | - | .34 |
| AD40 | .01 | -.01 | -.04 | .05 | .10 | .10 | .12 | .12 | .04 | .12 | .13 | .18 | .04 | .08 | .10 | .13 | .15 | .15 | .29 | .26 | .22 | .34 | - |
| Notes: AW1–AW15 are childhood anxiety/withdrawal items (see Table 1 in main paper for item descriptions); AD15–AD40 are DSM anxiety disorder outcomes at each assessment. | | | | | | | | | | | | | | | | | | | | | | | |

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Figure S1. Standardised (z-score) expected influence measure of childhood anxiety/withdrawal item (7–9 years) centrality in the male and female subsamples.



Figure S2. Adolescent anxiety disorder outcome networks (14–21 years) estimated with the Mixed Graphical Model procedure for the (a) male (*n* = 487) and (b) female (*n* = 495) subsamples.



Figure S3. Adult anxiety disorder outcome networks (21–40 years) estimated with the Mixed Graphical Model procedure for the (a) male (*n* = 459) and (b) female (*n* = 485) subsamples.



Figure S4. Adolescent anxiety disorder outcome network (14–21 years) for the (a) male (*n* = 487) and (b) female (*n* = 495) subsamples with all edges visualised.



Figure S5. Adult anxiety outcome network (21–40 years) for the (a) male (*n* = 459) and (b) female (*n* = 485) subsamples with all edges visualised.

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| Table S5. Mean bootstrapped edge weights (*n =* 1,000) between baseline childhood anxiety/withdrawal items (7–9 years) and anxiety disorder outcomes for males and females | | | | | |
|  |  | Mean (Pn-z) edge weight between each predictor and AD outcome | | | |
|  |  | Adolescent (14–21 years) AD | | Adult (21–40 years) AD | |
| Label | Description | Male | Female | Male | Female |
| AW1 | Afraid of new things or situations | **.012 (.383)** | .000 (.018) | .000 (.030) | -.002 (.072) |
| AW2 | Afraid of people | .002 (.094) | -.002 (.078) | .000 (.032) | -.004 (.115) |
| AW3 | Afraid of being left alone | **\*.055 (.797)** | -.001 (.033) | .004 (.147) | .003 (.116) |
| AW4 | Worries about illness or death | .000 (.033) | .016 (.415) | .003 (.107) | **.019 (.465)** |
| AW5 | Cries easily and often | **.024 (.552)** | .004 (.161) | .000 (.022) | **\*.057 (.887)** |
| AW6 | Often appears miserable | **.023 (.569)** | .002 (.084) | **\*.039 (.756)** | .006 (.220) |
| AW7 | Often worried | .000 (.014) | .**029 (.674)** | .012 (.364) | **.026 (.655)** |
| AW8 | Shy with other children | .008 (.262) | .000 (.041) | .003 (.123) | .000 (.039) |
| AW9 | Feelings easily hurt | .002 (.076) | **\*.052 (.838)** | -.001 (.058) | .007 (.238) |
| AW10 | Solitary, tends to do things alone | **\*.114 (.994)** | .000 (.029) | **\*.053 (.841)** | **.029 (.621)** |
| AW11 | Overly sensitive | .002 (.074) | .004 (.149) | **\*.036 (.710)** | .004 (.159) |
| AW12 | Overly serious or sad | .002 (.108) | .000 (.028) | **.017 (.475)** | **.022 (.581)** |
| AW13 | Submissive towards authority | .002 (.079) | .000 (.027) | .002 (.094) | -.002 (.076) |
| AW14 | Shy towards authority | .001 (.046) | **-.027 (.605)** | .000 (.027) | -.001 (.053) |
| AW15 | Fearful of authority | .009 (.309) | -.001 (.044) | .000 (.017) | .001 (.032) |
| Notes: 1. Edges estimated as non-zero in study sample are highlighted in bold; 2. Edges which were estimated as non-zero in >70% (Pn-z > .70) of bootstrapped models (*n* = 1,000 iterations) using both the GGM and MGM methodologies are denoted with an asterisk. | | | | | |

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