Supplemental Materials

Table S.1. Proportions of variance (on the diagonals) and covariance (off-diagonals) in pubertal development (PD) and substance use across adolescence and young adulthood due to additive genetic (A), common environmental (C) and unique environmental (E) factors, as estimated by the genetically-informative twin Cholesky models.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Additive Genetics (A) | | | | |  | Common Environment (C) | | | | |  | Unique Environment (E) | | | | |
| DRINKING FREQUENCY | | | | | | | | | | | | | | | | | | |
|  | Measure/Age | PD | 12 | 14 | 17 | 22 |  | PD | 12 | 14 | 17 | 22 |  | PD | 12 | 14 | 17 | 22 |
| Males | PD | 0.33\* |  |  |  |  |  | 0.37\* |  |  |  |  |  | 0.31\* |  |  |  |  |
| Age 12 | 0.57 | 0.17 |  |  |  |  | 0.19 | 0.57\* |  |  |  |  | -0.24 | 0.26\* |  |  |  |
| Age 14 | -0.21 | -0.15 | 0.56\* |  |  |  | 0.78\* | 0.77 | 0.10\* |  |  |  | 0.02 | 0.08 | 0.35\* |  |  |
| Age 17 | -0.44 | 0.25 | 0.21 | 0.06 |  |  | 0.52 | 0.65 | 0.67\* | 0.47\* |  |  | 0.04 | 0.10 | 0.13 | 0.47\* |  |
| Age 22 | -0.58 | -0.24 | -0.23 | -0.01 | 0.32\* |  | 0.38 | 0.32 | 0.60 | 0.46 | 0.07 |  | -0.04 | -0.43 | 0.17 | 0.53\* | 0.61\* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Females | PD | 0.59\* |  |  |  |  |  | 0.26\* |  |  |  |  |  | 0.15\* |  |  |  |  |
| Age 12 | 0.54 | 0.25 |  |  |  |  | -0.36 | 0.60\* |  |  |  |  | 0.10 | 0.15\* |  |  |  |
| Age 14 | 0.15 | 0.49 | 0.12\* |  |  |  | 0.68\* | 0.25 | 0.59\* |  |  |  | 0.17\* | 0.27 | 0.29\* |  |  |
| Age 17 | 0.32 | 0.11 | -0.08 | 0.40\* |  |  | 0.54 | 0.70 | 0.78\* | 0.24\* |  |  | -0.14 | -0.19 | 0.15\* | 0.36\* |  |
| Age 22 | -0.18 | -0.29 | 0.20 | 0.28 | 0.24 |  | 0.58 | 0.17 | 0.47 | 0.40 | 0.09 |  | -0.24 | -0.54 | 0.33 | 0.32\* | 0.67\* |
| ALCOHOL USE DISORDER SYMPTOMS | | | | | | | | | | | | | | | | | | |
|  | Measure/Age | PD | 14 | 22 |  |  |  | PD | 14 | 22 |  |  |  | PD | 14 | 22 |  |  |
| Males | PD | 0.33\* |  |  |  |  |  | 0.36\* |  |  |  |  |  | 0.30\* |  |  |  |  |
| Age 14 | 0.63 | 0.67\* |  |  |  |  | 0.32 | 0.02 |  |  |  |  | 0.05 | 0.32\* |  |  |  |
| Age 22 | -0.59 | 0.50 | 0.29\* |  |  |  | 0.38 | 0.16 | 0.16 |  |  |  | 0.03 | -0.34\* | 0.56\* |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Females | PD | 0.59\* |  |  |  |  |  | 0.26\* |  |  |  |  |  | 0.15\* |  |  |  |  |
| Age 14 | 0.55 | 0.02 |  |  |  |  | 0.44 | 0.56\* |  |  |  |  | -0.01 | 0.42\* |  |  |  |
| Age 22 | -0.42 | -0.18 | 0.28\* |  |  |  | 0.55 | 0.60\* | 0.12\* |  |  |  | 0.02 | 0.22 | 0.60\* |  |  |
| SMOKING FREQUENCY | | | | | | | | | | | | | | | | | | |
|  | Measure/Age | PD | 12 | 14 | 17 | 22 |  | PD | 12 | 14 | 17 | 22 |  | PD | 12 | 14 | 17 | 22 |
| Males | PD | 0.34\* |  |  |  |  |  | 0.36\* |  |  |  |  |  | 0.30\* |  |  |  |  |
| Age 12 | 0.42 | 0.28\* |  |  |  |  | -0.57 | 0.62\* |  |  |  |  | -0.01 | 0.10\* |  |  |  |
| Age 14 | 0.55 | 0.84 | 0.57\* |  |  |  | 0.28 | 0.16 | 0.23\* |  |  |  | 0.17 | 0.00 | 0.20\* |  |  |
| Age 17 | 0.59 | 0.48 | 0.47\* | 0.47\* |  |  | 0.17 | 0.45 | 0.41\* | 0.16\* |  |  | 0.23 | -0.07 | 0.12\* | 0.37\* |  |
| Age 22 | 0.46 | -0.04 | 0.30 | 0.51\* | 0.40\* |  | 0.40 | 0.87\* | 0.59\* | 0.33\* | 0.32\* |  | -0.14 | 0.09 | -0.10 | 0.15\* | 0.28\* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Females | PD | 0.59\* |  |  |  |  |  | 0.26\* |  |  |  |  |  | 0.15\* |  |  |  |  |
| Age 12 | 0.67 | 0.15 |  |  |  |  | 0.26 | 0.67\* |  |  |  |  | 0.07 | 0.18\* |  |  |  |
| Age 14 | 0.54 | -0.01 | 0.01 |  |  |  | 0.30 | 0.89\* | 0.75\* |  |  |  | 0.16 | 0.10 | 0.24\* |  |  |
| Age 17 | 0.63 | 0.00 | 0.01 | 0.37\* |  |  | -0.07 | 0.87\* | 0.84\* | 0.31\* |  |  | 0.30 | 0.13 | 0.15\* | 0.32\* |  |
| Age 22 | 0.79\* | -0.18 | 0.07 | 0.28\* | 0.23\* |  | -0.03 | 0.66\* | 0.77\* | 0.51\* | 0.43\* |  | -0.18 | 0.17\* | 0.15\* | 0.21\* | 0.34\* |
| ILLICIT DRUG USE | | | | | | | | | | | | | | | | | | |
|  | Measure/Age | PD | 17 | 22a | 22b |  |  | PD | 17 | 22a | 22b |  |  | PD | 17 | 22a | 22b |  |
| Males | PD | 0.33\* |  |  |  |  |  | 0.37\* |  |  |  |  |  | 0.30\* |  |  |  |  |
| Age 17 | 0.65 | 0.56\* |  |  |  |  | -0.34 | 0.18\* |  |  |  |  | 0.00 | 0.26\* |  |  |  |
| Age 22a | 0.62 | 0.92\* | 0.66\* |  |  |  | -0.08 | 0.07 | 0.06 |  |  |  | 0.30 | 0.02 | 0.27\* |  |  |
| Age 22b | 0.74 | 0.84\* | 0.70\* | 0.37\* |  |  | -0.14 | -0.13 | 0.03 | 0.04 |  |  | -0.13 | 0.03 | 0.27\* | 0.58\* |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Females | PD | 0.59\* |  |  |  |  |  | 0.26\* |  |  |  |  |  | 0.15\* |  |  |  |  |
| Age 17 | 0.55 | 0.37\* |  |  |  |  | 0.30 | 0.09\* |  |  |  |  | 0.15 | 0.54\* |  |  |  |
| Age 22a | -0.31 | 0.61\* | 0.32\* |  |  |  | 0.60 | 0.17\* | 0.16\* |  |  |  | 0.09 | 0.22\* | 0.52\* |  |  |
| Age 22b | -0.44\* | 0.31\* | 0.25\* | 0.12\* |  |  | 0.39\* | 0.42\* | 0.46\* | 0.44\* |  |  | 0.16\* | 0.27\* | 0.28\* | 0.45\* |  |

*Note: Negative values represent instances of negative covariance between traits; absolute values were used to calculate proportions. Shaded cells contain estimates of the covariance between pubertal development and substance use. \* p < .05; a Cannabis use; b other illicit drug use.*

Table S.2. Model fit comparisons for two-level structural equation models of the relationship between age 12 pubertal development (PD) and adolescent/young adult substance use. For each model, two variations of sex effects are tested: males (M) and females (F) analyzed separately in multi-group model, or regression path estimates for males and females constrained to equality.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Measures | -2LL | AIC | BIC | aBIC | Δ df | Likelihood ratio test *p* |
| *Drinking frequency* |  |  |  |  |  |  |
| M/F paths estimated separately | -31543.932 | 63467.86 | 64645.40 | 64041.67 | -- | -- |
| M/F paths constrained equal | -31608.937 | 63463.874 | 64226.172 | 63835.339 | 67 | 1.3e-05 |
| *Alcohol use disorder symptoms* |  |  |  |  |  |  |
| M/F paths estimated separately | -19241.572 | 38759.14 | 39614.33 | 39175.83 | -- | -- |
| M/F paths constrained equal | -19285.583 | 38753.165 | 39317.091 | 39027.939 | 67 | 2.2e-05 |
| *Smoking frequency* |  |  |  |  |  |  |
| M/F paths estimated separately | -43631.504 | 87643.01 | 88820.54 | 88216.82 | -- | -- |
| M/F paths constrained equal | -43687.668 | 87621.336 | 88383.633 | 87992.800 | 67 | 0.0054 |
| *Illicit drug use* |  |  |  |  |  |  |
| M/F paths estimated separately | -33702.817 | 67761.63 | 68864.80 | 68299.20 | -- | -- |
| M/F paths constrained equal | -33780.368 | 67792.737 | 68511.651 | 68143.061 | 67 | 2.1e-06 |

*Note: Shaded blocks indicate groupings of models whose fit was compared to evaluate sex differences. Likelihood ratio test calculated for use with the MLR estimator, as recommended by Muthén & Muthén (2012). -2LL = minus twice the model loglikelihood; AIC = Akaike’s Information Criteria, BIC = Bayesian Information Criteria, aBIC = sample size-adjusted BIC, df = degrees of freedom.*

Table S.3. Between-and within-family regression associations from the multi-level structural equation model (Fig 2, ‘b’ paths) between age 12 pubertal development (PD) and peer substance use (Peer) and parental monitoring (Mon) in adolescence.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Between Families | | Within Families | |
|  | Males | Females | Males | Females |
| Peer14 | 0.20\*\* | 0.15\*\* | 0.00 | -0.02 |
| Peer17 | 0.13\* | 0.14\*\* | 0.06 | -0.01 |
| Mon12 | -0.25\*\* | -0.05 | -0.01 | -0.11\*\* |
| Mon14 | -0.18\*\* | -0.05 | -0.08 | -0.14\*\* |

*\*p < .05; \*\*p < .01*

Table S.4. Direct regression effects of peer substance use (Peer) and parental monitoring (Mon) predicting substance use (SU) measures across adolescence and young adulthood, from the multilevel structural equation model (Fig. 2, ‘c’ paths).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Between Families | | Within Families | |
|  | Males | Females | Males | Females |
| DRINKING FREQUENCY | | | | |
| Peer14 → SU14 | 0.45\*\*\* | 0.45\* | 0.18\*\*\* | 0.32\*\*\* |
| Peer14 → SU17 | -0.49 | 0.00 | 0.09 | -0.03 |
| Peer17 → SU17 | 1.67\*\*\* | 1.34\* | 0.60\*\*\* | 0.74\*\*\* |
| Peer14 → SU22 | -0.78 | 0.40 | -0.20 | 0.03 |
| Peer17 → SU22 | 1.39 | -0.21 | 0.61 | 0.60\* |
|  |  |  |  |  |
| Mon12 → SU12 | -0.04 | -0.10\* | -0.07\*\*\* | 0.01 |
| Mon12 → SU14 | 0.17 | 0.06 | -0.04 | -0.01 |
| Mon14 → SU14 | -0.27\*\* | -0.37\* | -0.09 | -0.11\* |
| Mon12 → SU17 | -0.54 | -0.38 | 0.13 | 0.24\* |
| Mon14 → SU17 | 0.55 | 0.08 | -0.30\* | -0.05 |
| Mon12 → SU22 | -0.82 | -0.09 | -0.33 | 0.16 |
| Mon14 → SU22 | 0.33 | 0.05 | -0.29 | 0.04 |
| ALCOHOL USE DISORDER SYMPTOMS | | | | |
| Peer14 → SU14 | 0.17\*\* | 0.30\*\*\* | 0.09\*\*\* | 0.15\*\*\* |
| Peer14 → SU22 | -0.25 | -0.22 | 0.11\* | 0.40\*\*\* |
| Peer17 → SU22 | 0.46\* | 0.62\*\*\* | 0.24\*\*\* | -0.06 |
|  |  |  |  |  |
| Mon12 → SU14 | 0.05 | -0.23 | -0.06\* | 0.09\* |
| Mon14 → SU14 | -0.20 | -0.08 | -0.01 | -0.17\*\*\* |
| Mon12 → SU22 | 0.16 | -0.23 | 0.10 | -0.10 |
| Mon14 → SU22 | -0.17 | -0.07 | -0.25\*\*\* | -0.13 |
| SMOKING FREQUENCY | | | | |
| Peer14 → SU14 | 0.73\*\*\* | 0.90\*\*\* | 0.27\*\*\* | 0.28\*\*\* |
| Peer14 → SU17 | 0.32 | 1.67 | -0.14 | -2.52 |
| Peer17 → SU17 | 15.62\*\*\* | 13.38\*\*\* | 8.70\*\*\* | 6.46\*\*\* |
| Peer14 → SU22 | -4.17 | 1.42 | 0.69 | 2.00 |
| Peer17 → SU22 | -0.64 | -1.52 | 3.80 | 0.81 |
|  |  |  |  |  |
| Mon12 → SU12 | -0.18\*\*\* | -0.13\*\* | -0.02 | 0.01 |
| Mon12 → SU14 | -0.12 | 0.30 | 0.12 | 0.03 |
| Mon14 → SU14 | -0.24 | -0.58\*\* | -0.09 | -0.23\*\* |
| Mon12 → SU17 | -1.95 | -0.89 | 2.57 | 3.03 |
| Mon14 → SU17 | -3.13 | -3.13 | -0.31 | -0.79 |
| Mon12 → SU22 | 7.37 | -4.59 | -3.90 | -0.21 |
| Mon14 → SU22 | -8.48 | 9.62\* | -0.51 | -2.88 |
| ILLICIT DRUG USE | | | | |
| Peer14 → SU17 | 0.33 | 0.39\* | 0.03 | 0.29 |
| Peer17 → SU17 | 1.24\*\*\* | 0.70\*\*\* | 0.36\* | 0.99\*\*\* |
| Peer14 → SU22a | 0.11 | -0.06 | 0.24 | -0.42 |
| Peer17 → SU22a | 1.19\*\* | 0.31 | 0.29 | 0.46\* |
| Peer14 → SU22b | 0.24 | -0.33 | -0.16 | 0.25 |
| Peer17 → SU22b | 0.36 | -0.06 | -0.15 | 0.04 |
|  |  |  |  |  |
| Mon12 → SU17 | -0.01 | -0.08 | -0.10 | 0.29 |
| Mon14 → SU17 | -0.13 | -0.63\* | 0.06 | -0.49\* |
| Mon12 → SU22a | 0.39 | -0.64 | -0.08 | 0.25 |
| Mon14 → SU22a | -0.36 | 0.90\* | -0.02 | -0.71\*\*\* |
| Mon12 → SU22b | 0.02 | -0.38 | -0.28\* | -0.17 |
| Mon14 → SU22b | -0.14 | 0.46 | -0.30\* | -0.41\* |

*Note: a Cannabis use; b other illicit drug use. \* p < .05, \*\*p < .01, \*\*\*p < .001.*

Table S.5. Comparison of the between-family effects of age 12 pubertal development (PD) on substance use in a multi-level structural equation model with or without including the effect of biological father absence (FA) as a predictor of PD, substance use, peer substance use, and parental monitoring.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Males | |  | Females | |
| Age | Without FA | With FA |  | Without FA | With FA |
| DRINKING FREQUENCY | | | | | |
| 12 | 0.01 (0.01) | 0.01 (0.01) |  | 0.01 (0.01) | 0.01 (0.01) |
| 14 | 0.08 (0.11\*) | 0.09 (0.09\*) |  | 0.09\* (0.09\*\*\*) | 0.09\* (0.09\*\*\*) |
| 17 | -0.09 (0.38\*) | -0.09 (0.34\*) |  | -0.12 (0.25\*\*\*) | -0.12 (0.25\*\*\*) |
| 22 | 0.1 (0.29) | 0.06 (0.25) |  | 0.04 (0.10) | 0.04 (0.10) |
| ALCOHOL USE DISORDER SYMPTOMS | | | | | |
| 14 | 0.01 (0.05\*) | 0.02 (0.05\*) |  | 0.12\* (0.06\*\*) | 0.12\* (0.06\*\*) |
| 22 | 0.06 (0.07) | 0.05 (0.06) |  | 0.11 (0.09\*) | 0.11 (0.09\*) |
| SMOKING FREQUENCY | | | | | |
| 12 | -0.05 (0.05\*\*) | -0.07 (0.04\*\*) |  | 0.06\* (0.01) | 0.06\* (0.01) |
| 14 | 0 (0.22\*\*) | -0.01 (0.19\*) |  | 0.00 (0.24\*\*) | 0.00 (0.24\*\*) |
| 17 | 0.16 (4.98\*\*) | -0.09 (4.12\*) |  | -2.61 (4.01\*\*\*) | -2.56 (3.84\*\*\*) |
| 22 | 10.38\* (5.4) | 10.35\* (3.91) |  | 3.17\* (1.29) | 3.18\* (1.10) |
| ILLICIT DRUG USE | | | | | |
| 17 | -0.11 (0.24\*) | -0.11 (0.20) |  | -0.02 (0.19\*\*) | -0.02 (0.18\*\*) |
| 22a | 0.51 (0.23) | 0.51 (0.17) |  | 0.11 (0.24) | 0.11 (0.23) |
| 22b | 0.15 (0.12) | 0.14 (0.10) |  | 0.09 (0.11) | 0.09 (0.11) |

*Note: Direct effects of PD on substance use at each age are shown, with indirect effects (through autoregressive effects on previous substance use and through mediational paths) in parentheses. \*p < .05; \*\*p < .01, \*\*\*p < .001. a Cannabis use; b other illicit drug use.*