**Supplementary Material**

**I. Development of Single-Factor Models for Delinquent Behaviors and SUDs**

*Rationale.* For delinquent behaviors and SUDs, we sought to examine whether trends in each set of outcomes could be described as a trend in an underlying latent trait, related to predisposition to delinquency and SUDs, respectively. This section describes steps in the development of the single-factor models for delinquency (DQ) and SUDs.

*Methods.* We conducted exploratory factor analyses (EFA) to verify that the DQ and SUD constructs were unidimensional and accounted for large portions of the item variance. This was done in MPlus specifying the outcome variables as categorical (binary) indicators. To ensure that the dimensionality did not change over time, we conducted EFA for the full 2003-2014 combined sample and for six samples combined over windows two consecutive years (2003/4, 2005/6, etc.). We chose to combine analyses over two consecutive years rather than analyze single-year samples to simplify presentation of result (i.e., 6 samples vs. 12).

We then analyzed each construct using IRT 2-parameter logistic models (2PL), which yield estimates of an item discrimination coefficient or slope, and difficulty parameter, or intercept. The item discrimination coefficient describes the strength of the association between the observed variable and the latent trait, whereas the difficulty parameter is a measure of the frequency of the item in relation to the latent trait. That is, behaviors described by items with high difficulty parameters are rarer at any given value of the latent trait than items with lower difficulty parameters.

*Results.* Exploratory analysis showed that a single-factor model for delinquency measures accounted for 60% of the total variance among the items in the combined sample. A single factor accounted for 68% of the total variance among SUD items. Eigenvalues and correspoinding R2 are listed in Table S1. Factor loadings are listed in Table S2. Eigenvalues and factor loadings for all of the two year samples closely resembled those for the overall sample and did not vary appreciably over time (with the pssible exception of the factor loadings for the gun-carrying item). The high degree of variance accounted for by the first factor, coupled with the relatively high ratio of first to second Eigenvalues in each case provide evidence that the constructs can reasonably be viewed as unidimensional.[[1]](#footnote-1) Parameters for the single-factor IRT models are provided in Table S3.

*Conclusion.* Single-factor IRT models describing the six delinquency items and the six SUD outcomes each as a function of their respective underlying latent trait accounted for high portions of the variance among items and exhibited strong measurement invariance over time (see main text Results). This suggests that trends in the individual outcomes correspond to trends in the mean-levels of the latent traits.

**II. Development of the EXT model**

*Rationale.* After establishing measurement invariance for each of the one-factor models, our next objective was to determine whether trends in both delinquent behaviors and SUDs could be viewed as trends in an Externalizing-like trait. This might reflect a process in which a higher-order Externalizing factor (EXT) has direct influence on all outcomes (e.g., Figure S1, Panel A) or acts on sub-factors related to delinquency (DQ) and substance-use disorder (SUD) outcomes (Figure S1, Panel B). However, the latter model is under-identified, because the only information about the parameters describing the influences of the EXT factor on the two lower-order DQ and SUD factors come from the single correlation coefficient describing the relation between DQ and SUD. Therefore, we used the one-factor EXT model for our final analyses in the main manuscript. Below we describe the characteristics of this model relative to a model in which the two latent factors DQ and SUD are correlated with each other (Figure S1, Panel C). Note that this latter model is a re-parameterization of the hierarchical model drawn in Figure S1, Panel A.

*Results.*In an EFA of the 12 items (6 delinquent behaviors and 6 SUDs), the first factor described 53% of the variance (Eigenvalue=6.3); this result varied little when analyses were conducted in the six, two-year subsamples described above (range=51.5% to 54.0%). A second factor described an additional 12.5% (Eigenvalue=1.5), the third through twelfth factors all had Eigenvalues lower than 1 and described 7% or less of the variance. The two correlated factor model (DQ ↔ SUD; Figure S1C) exhibited better fit than the one-factor EXT model; BIC=1,865,315 vs. 1,872,556; CFI=0.961 vs. 0.946. However, in the two factor model, the DQ and SUD factors were highly correlated (R=0.74 for all years combined; ranging 0.68 to 0.77 when estimated separately by year).

Given the identification issues with the hierarchical model, we accepted the incrementally poorer fit of the single-factor EXT model, which still accounts for more than half of the variance among items. This allowed us to conduct measurement invariance tests parallel to those conducted for the SUD and DQ models (Main text, Table 3). IRT parameters for the single-factor EXT model are listed in Table S4.

**Part III. Estimation of Factor Means**

 To estimate the factor means for the DQ, SUD, and EXT factors by year, we estimated the models described in the main text, in which item discriminations and coefficients were held constant across years, factor variances were fixed at 1 and mean values for latent traits were estimated freely for each year, except for 2003 which serves as the reference year for which the mean is set to zero . Factor means are plotted as a function of year in Figure S2. This yields mean estimtes on a z-score or standard-normal metric. The plot reveals that both the DQ and SUD factors declined by about one-third of a standard deviation across the years 2003-2014 and that the EXT factor declined by nearly 0.4 standard deviations.

**Part IV: Handgun-carrying in relation to other delinquency behaviors**

As discussed in the main body of the text, the prevalence of handgun-carrying did not decline between 2003 and 2014.Yet the structural analyses suggest that the six delinquency items taken together serve as markers for a single underlying factor that underwent a temporal decline, thus leading to a decline in prevalence for all of the other 5 behaviors in both age groups.

One interpretation for this is that the proportion of variance in handgun-carrying that is attributable to delinquency declined over the 2003-2014 period, but that this change in association between the latent factor and the manifest indicator was relatively small. For this reason, the assumption that the item discrimination coefficient and difficulty parameters remained constant over time did not substantially worsen the model fit. In terms of manifest behavior, this would suggest that the prevalence of handgun-carrying as an individual behavior, unrelated to delinquency, underwent an increase during this period. We analyzed this graphically by plotting the prevalence of handgun-carrying without other delinquent behaviors and the prevalence of handgun-carrying with one or more other delinquent behaviors, for both age groups combined. The results are shown in Figure S3 and are consistent with that interpretation: the prevalence of handgun-carrying as a standalone behavior appears to have risen whereas the prevalence of handgun-carrying in the context of delinquency has declined.

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| **Table S1:** Eigenvalues / R2 values from separate exploratory factor analyses of delinquent behaviors and SUDs overall and by two-year intervals. |
|  | **Eigenvalues** | **R-Squared** |
| **Delinquent****Behavior** | **All Years** | **2003/4** | **2005/6** | **2007/8** | **2009/10** | **2011/12** | **2013/14** | **All Years** | **2003/4** | **2005/6** | **2007/8** | **2009/10** | **2011/12** | **2013/14** |
| First Factor | 3.57 | 3.58 | 3.60 | 3.58 | 3.64 | 3.55 | 3.44 | 0.60 | 0.60 | 0.60 | 0.60 | 0.61 | 0.59 | 0.60 |
| Second Factor | 0.86 | 0.84 | 0.85 | 0.88 | 0.84 | 0.84 | 0.90 | 0.14 | 0.14 | 0.14 | 0.15 | 0.14 | 0.14 | 0.14 |
| Third Factor | 0.50 | 0.47 | 0.49 | 0.47 | 0.49 | 0.54 | 0.58 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.09 | 0.08 |
| Fourth Factor | 0.43 | 0.43 | 0.43 | 0.42 | 0.42 | 0.44 | 0.45 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| Fifth Factor | 0.35 | 0.36 | 0.35 | 0.34 | 0.33 | 0.35 | 0.36 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| Sixth Factor | 0.30 | 0.32 | 0.31 | 0.30 | 0.29 | 0.29 | 0.29 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| **SUDs** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| First Factor | 4.10 | 4.10 | 4.10 | 4.10 | 4.20 | 4.20 | 4.00 | 0.68 | 0.68 | 0.68 | 0.68 | 0.70 | 0.70 | 0.68 |
| Second Factor | 0.71 | 0.76 | 0.77 | 0.74 | 0.66 | 0.62 | 0.73 | 0.12 | 0.13 | 0.13 | 0.12 | 0.11 | 0.10 | 0.12 |
| Third Factor | 0.42 | 0.45 | 0.42 | 0.40 | 0.43 | 0.42 | 0.45 | 0.07 | 0.08 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| Fourth Factor | 0.30 | 0.35 | 0.31 | 0.30 | 0.28 | 0.32 | 0.31 | 0.05 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Fifth Factor | 0.29 | 0.26 | 0.26 | 0.27 | 0.26 | 0.28 | 0.30 | 0.05 | 0.04 | 0.04 | 0.05 | 0.04 | 0.05 | 0.05 |
| Sixth Factor | 0.19 | 0.18 | 0.18 | 0.19 | 0.17 | 0.16 | 0.22 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
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| **Table S2:** Factor loadings from separate exploratory factor analyses of delinquent behaviors and SUDs overall and by two-year intervals. |
|  | **Factor Loadings** |
| **Delinquent****Behavior** | **All Years** | **2003/4** | **2005/6** | **2007/8** | **2009/10** | **2011/12** | **2013/14** |
| Serious Fight | 0.73 | 0.73 | 0.73 | 0.73 | 0.75 | 0.72 | 0.73 |
| Group Fight | 0.76 | 0.75 | 0.77 | 0.77 | 0.76 | 0.74 | 0.74 |
| Attack to Injure | 0.77 | 0.76 | 0.76 | 0.76 | 0.77 | 0.77 | 0.75 |
| Stealing Item >$50 | 0.72 | 0.70 | 0.71 | 0.71 | 0.73 | 0.75 | 0.73 |
| Selling Drugs | 0.74 | 0.73 | 0.74 | 0.73 | 0.76 | 0.76 | 0.74 |
| Hand Gun Carrying | 0.63 | 0.68 | 0.65 | 0.67 | 0.65 | 0.60 | 0.54 |
| **SUDs** |  |  |  |  |  |  |  |
| Alcohol  | 0.68 | 0.67 | 0.68 | 0.68 | 0.69 | 0.71 | 0.66 |
| Nicotine | 0.80 | 0.79 | 0.80 | 0.81 | 0.81 | 0.79 | 0.81 |
| Marijuana | 0.84 | 0.87 | 0.84 | 0.85 | 0.83 | 0.81 | 0.81 |
| Analgesics | 0.81 | 0.78 | 0.80 | 0.82 | 0.83 | 0.82 | 0.79 |
| Other Non-Prescription Drugs | 0.85 | 0.85 | 0.86 | 0.82 | 0.87 | 0.90 | 0.82 |
| Other Prescription Drugs | 0.81 | 0.78 | 0.82 | 0.82 | 0.82 | 0.82 | 0.81 |
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| **Table S3:** Parameter estimates from single-factor IRT models for delinquency (top) and SUDs (bottom) combining all years of data. N=210,599 |
|  | **Item Discrim. Coeff. (S.E.)** | **Difficulty** |
| Serious Fight | 1.99 (0.03) | 1.07 (0.01) |
| Group Fight | 2.14 (0.03) | 1.38 (0.01) |
| Attack to Injure | 2.16 (0.03) | 1.92 (0.01) |
| Stealing Item >$50 | 1.81 (0.03) | 2.47 (0.02) |
| Selling Drugs | 1.92 (0.03) | 2.58 (0.03) |
| Hand Gun Carrying | 1.49 (0.03) | 2.89 (0.03) |
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| Alcohol  | 1.91 (0.04) | 2.57 (0.03) |
| Nicotine | 2.59 (0.05) | 2.06 (0.01) |
| Marijuana | 3.01 (0.05) | 2.14 (0.01) |
| Analgesics | 2.59 (0.08) | 2.91 (0.04) |
| Other Non-Prescription Drugs | 3.03 (0.10) | 3.03 (0.04) |
| Other Prescription Drugs | 2.90 (0.09) | 2.82 (0.03) |

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| **Table S4:** Parameter estimates from single-factor IRT models for delinquency (top) and SUDs (bottom) combining all years of data. N=210,599 |
|  | **Item Discrim. Coeff. (S.E.)** | **Difficulty** |
| Serious Fight | 1.51 (0.02) | 1.06 (0.02) |
| Group Fight | 1.68 (0.02) | 1.37 (0.02) |
| Attack to Injure | 1.89 (0.03) | 2.79 (0.03) |
| Stealing Item >$50 | 2.06 (0.03) | 2.01 (0.02) |
| Selling Drugs | 3.02 (0.05) | 2.15 (0.02) |
| Hand Gun Carrying | 1.43 (0.02) | 1.87 (0.02) |
| Alcohol  | 1.86 (0.03) | 2.59 (0.03) |
| Nicotine | 1.66 (0.03) | 2.18 (0.03) |
| Marijuana | 2.33 (0.04) | 2.15 (0.02) |
| Analgesics | 2.16 (0.06) | 2.96 (0.05) |
| Other Non-Prescription Drugs | 2.50 (0.07) | 3.06 (0.05) |
| Other Prescription Drugs | 2.54 (0.07) | 2.78 (0.04) |



C

B

A

Figure S1: Structural models describing three possible factor structures for delinquent behaviors and substance use disorders (SUD). Model A represents a single Externalizing factor. Model B represents hierarchical structure, in which a single factor influences two sub-factors DQ and SUD. Model C is illustrated as an alternative specification of the hierarchical model and was used for quality-of-fit comparison with Model A.

Figure S2: Estimated factor means for the DQ, SUD and EXT factors, by year, 2003-2014. Error bars represent 95% confidence intervals.

**Figure S3.** Prevalence of handgun carrying with one or more other delinquent behaviors (open symbols) and prevalence of handgun carrying without other delinquent behaviors (filled symbols) among 12-17 year olds, 2003-2014.

1. Ronald K Hambleton and Hariharan Swaminathan, *Item Response Theory: Principles and Applications*, vol. 7 (Springer Science & Business Media, 1985). [↑](#footnote-ref-1)