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Modeling the impact of age and sex on a dimension of poly-substance use in adolescence: A longitudinal study from 11- to 17-years-old

Jaime Derringer¹, Robert F. Krueger¹, William G. Iacono², and Matt McGue²

¹ Department of Psychology, Washington University, Campus Box 1125, St. Louis MO 63130

² Department of Psychology, University of Minnesota, N218 Elliott Hall, 75 East River Road, Minneapolis MN 55455

Abstract

We examined the conceptual utility of modeling use of multiple substances as a trait represented by a unified dimension throughout adolescence. Adolescents (710 males and 676 females) participating in a longitudinal community study were asked whether they had used alcohol, tobacco, marijuana, other controlled substances, or uncontrolled substances (i.e., over-the-counter medications and inhalants) at ages 11, 14, and 17. Using an item response theory framework, model fit indices demonstrated that although all substance use remained part of a single latent dimension, model parameters differed with age and according to sex. The impact of sex was observed at the level of the overall dimension, with reported substance use generally indicating a higher trait level (i.e., greater severity) in females than in males. While using these substances provided good information on individual trait level in mid- to late-adolescence, the trait was poorly characterized by substance use in early adolescence. Across ages and sexes, use of alcohol and tobacco tended to indicate lower trait levels than use of marijuana, other controlled substances, and uncontrolled substances. All substances provided a similar amount of information on the underlying dimension (except for uncontrolled substances, which provided the least information). This suggests that measurement and interpretation of adolescent substance use is enhanced by the consideration of a wide range of substances.

Keywords

substance use; item response theory; adolescence; sex differences

1. Introduction

Most variance in use and misuse of various substances is accounted for by common (rather than substance-specific) genetic and environmental factors (Hall & Lynskey, 2005; Kendler et al., 2003). Nevertheless, much of the literature treats substances as distinct entities (e.g.

Corresponding author: Jaime Derringer, Department of Psychology, Washington, University, Campus Box 1125, St. Louis MO 63130 USA. Phone: +1-314-935-3344; Fax: +1-314-935-7588; derringer@wustl.edu.

Contributors

Ms. Derringer and Dr. Krueger designed and undertook the statistical analysis. Ms. Derringer managed the literature searches and summaries of previous related work and wrote the first draft of the manuscript. Drs. Krueger, Iacono, and McGue assisted with the preparation and proof-reading of the manuscript. All authors contributed to and have approved the final manuscript.

Conflict of Interest

All authors declare that they have no conflicts of interest.

Kahler et al., 2004; Kashdan et al., 2005; Saha et al., 2006; Wallace et al., 2003). We evaluated the utility of modeling involvement with multiple substances in terms of a unifying poly-substance dimension. Specifically, we evaluated a dimensional conceptualization of poly-substance use in a longitudinal study that followed male and female participants from ages 11 to 17. To understand the construct validity of this dimensional conceptualization, we modeled the impact of age and sex on the properties of the dimension. Rather than impacting specific substances individually, age and sex may impact properties of a unifying substance involvement dimension (e.g., being male may increase risk for involvement with multiple substances, which could be modeled as a sex effect on the entire dimension, transcending specific substances). This would support conceptualizing adolescent substance use in terms of a unifying poly-substance dimension, and focusing longitudinal research on this dimension, as well as the ways in which this dimension manifests more specifically in individual substance classes. Item response theory provides the quantitative infrastructure needed to evaluate this dimensional conceptualization.

1.1 Item Response Theory Modeling

Item response theory (IRT) modeling provides a quantitative tool for mapping involvement with multiple substances onto an underlying dimension. A two-parameter logistic IRT model is defined by item discrimination (a) and item location (b) parameters for each item. These parameters indicate how each item relates to the underlying dimension (see Embretson & Reise, 2000, for a thorough description of IRT).

A benefit of IRT when applied to poly-substance use involvement is the ability to observe information provided by individual substances and the measure as a whole for all levels of poly-substance use involvement. Item information functions (IIFs), derived from discrimination and location parameters, indicate information on poly-substance use involvement provided by each substance or class of substances and are summed to form the test information curve (TIC).

1.2 IRT Applications to Substance Involvement

The majority of substance use IRT models have been applied to modeling DSM criteria corresponding to specific substances (Gillespie et al., 2007; Harford et al., 2009; Langenbucher et al., 2004; Martin et al., 2006; Saha et al., 2006) or other measures of specific substance-related problems (Alterman et al., 2007; Kahler et al., 2003; Kahler et al., 2004; Kirisci et al., 1994; Krueger et al., 2004; Neal et al., 2006). These studies find that items tend to indicate greater levels of substance misuse severity in females than in males (Kahler et al., 2004; Martin et al., 2006) and greater severity in younger samples compared to older samples (Neal et al., 2006). That is, in females and younger persons, endorsement of items such as DSM criteria indicated a more severe level of substance misuse. These single-substance studies represent an important starting point for conceptualizing the potential effects of age and sex on poly-substance use.

Few studies have utilized IRT to compare multiple substances as part of a single dimension. In a study of poly-substance disorder severity, Kirisci and colleagues (2006) found that substance use diagnoses displayed different location and discrimination parameters between sexes (husbands and wives) as well as between ages (fathers and adolescent sons). As with models of substance-specific DSM criteria, disorder diagnoses indicated greater trait severity and provided more information in adult females and adolescent males than in adult males.

Utilizing IRT models to investigate adult lifetime poly-substance use, Kirisci and colleagues (2002) found significant differences in substance location and discrimination between males and females for each of ten substances. Though the relative rank ordering of substances'

locations remained the same between sexes (e.g., alcohol use indicated the lowest trait level, though tobacco use was not modeled), individual substances indicated higher trait levels for females than for males, regardless of the substance. Additionally, all substances provided greater information for males than females. These findings support the presence of a general poly-substance use dimension that differs by sex in adults, but do not speak to the structure of poly-substance use in adolescence, or the potential impact of age and sex on that dimension during that period. Because experimentation with substances typically develops during adolescence, understanding the nature of poly-substance use around this time would be a useful extension.

1.3 The current study

While previous studies examined age and sex effects on overall substance use in the context of disordered use (Kirisci et al., 2006) and adult use (Kirisci et al., 2002), an IRT framework has not yet been applied to examine both developmental and sex effects on poly-substance use in a longitudinal, community-based adolescent sample. This is an important gap in the literature because adolescence is the period most critical to understanding the emergence of substance use. To fill this gap, the present study aimed to understand how specific substances relate to an underlying dimension of poly-substance use involvement, and whether use of different substances is well-conceptualized as a single latent trait. We examined interpretations of the use of substances between age and sex groups, as well as the ways in which age and sex affect the structure and information provided by the poly-substance use dimension.

2. Methods

2.1 Participants

The sample consisted of participants from the younger cohort in the longitudinal Minnesota Twin Family Study (MTFS, see Iacono & McGue, 2002). Participants are identified by the target age for their intended assessment: 11-years-old ($M=11.70$, $SD=0.43$) at intake, 14-years-old ($M=14.77$, $SD=0.51$) at the first follow-up, and 17-years-old ($M=17.99$, $SD=0.60$) at the second follow-up. The final sample of those who were administered the relevant measure in person included 710 males and 676 females at intake. At first follow-up, 608 males and 648 females completed the measure and data were available from 493 males and 504 females at second follow-up.

Attrition effects in the current study were examined in Mplus (Muthén & Muthén, 1998–2007) by regressing substance use endorsement counts (the sum of the five substance categories examined) on whether individuals returned for later assessments (controlling for the non-independent nature of twin data). The only significant effect indicated that males who did not complete the 17-year-old follow-up had used more substances by age 14 than those who did ($r=0.36$, $z=2.16$, $p=0.03$, *Cohen's d*=0.25). Attrition is therefore unlikely to meaningfully impact our findings.

2.2 Measure

At 11-, 14-, and 17-year-old time-points, a computerized substance use questionnaire was individually self-administered, without the presence of project staff. Questions were phrased as, "Have you ever used [substance]?" Estimation of IRT parameters requires that at least one person per group endorses each item (in this case, groups were defined by age, sex, and twin birth order). To achieve this in each group and to maintain conformity across substances, responses to use of each substance were converted to dichotomous yes/no values (original response options differed between substances) and substances with lower endorsement rates were clustered into substance classes. The final measure analyzed here was which substances (tobacco, alcohol, and marijuana) or classes of substances [other controlled substances

(stimulants, tranquilizers, Quaaludes/downers, cocaine, PCP/LSD/other psychedelics, and opiates) and uncontrolled substances (over-the-counter medications and inhalants)] the participant endorsed having ever used (at the intake assessment) or used since the previous assessment (at each follow-up) recreationally. This approach is useful in this context as it retains variance at all ages (which is especially challenging when dealing with the relatively low usage rates among 11-year-olds). Additionally, the analysis of less quantitatively-specific responses may increase reliability, especially when participants are asked about use over a longer period of time (Hays & Huba, 1988).

2.3 Statistical analyses

All analyses were conducted in Mplus (Muthén & Muthén, 1998–2007). IRT models were derived from a single-factor model, with latent trait group means set to 0, latent variances set to 1, and scale factors set to 1, using the program-default weighted least squares estimator (WLSMV). Parameter estimates were made using a two-parameter logistic IRT model and were calculated directly from factor parameters (Muthén & Asparouhov, 2002).

To understand age and sex effects on poly-substance use involvement, substance endorsement data were split by age and sex for multigroup IRT model estimation. As the technical limitations of the model being used did not allow for explicitly accounting for the clustered nature of twin data, we chose to treat first- and second-born twins as an additional group designation and test for “birth order effects” by equating parameters across twins. This resulted in IRT parameters (substance locations and discriminations) being estimated for 12 groups total (2 sexes $\times$ 3 ages $\times$ 2 twins).

An initial, unconstrained model was fit in which substance locations and discriminations were estimated independently for each age-by-sex-by-twin group. Additional models were calculated in which estimates of substance locations and/or discriminations were constrained to be equal across ages and/or sexes. Each model was then also evaluated for whether parameter estimates could be constrained equal across twins. Models were evaluated for goodness-of-fit by examining their comparative fit index (CFI), Tucker-Lewis index (TLI), and root mean square error of approximation (RMSEA). The best-fitting model was identified as the one with the highest CFI and TLI and the lowest RMSEA. (Note: Due to the WLSMV estimator, model fits could not be compared via conventional chi-square difference tests, Muthén & Muthén, 1998–2007.)

Based on the parameters of the best-fitting model, a number of substance- and measure-level information graphs were derived. Item response functions (IRFs), indicating the probability of a person with any given trait level endorsing having used a substance, are calculated as $p_i(\theta) = [e^{a_i(\theta-b_i)}] / [1 + e^{a_i(\theta-b_i)}]$, where θ is a Z-scored trait level, a is the discrimination of the substance (or the slope at the center point where $p_i(\theta)=0.5$), and b is the substance location (the horizontal placement of the center point on a z-score scale). Item information functions (IIFs), indicating the information provided by each substance at any trait level, are calculated as $I_i(\theta) = a_i^2 p_i(\theta) q_i(\theta)$, where q_i is $1-p_i$. Information provided by the entire measure at each trait level is given by the test information function (TIC; $T(\theta) = \sum I_i(\theta)$). Finally, the standard error of measurement (SEM) at every trait level is $SE(\theta) = 1/T(\theta)^{1/2}$ (Embretson & Reise, 2000).

3. Results

We utilized multigroup IRT to model the effect of age, sex, and birth order on endorsement rates for each substance/class, which are shown in Table 1. For the sake of completeness, models representing all possible combinations of constraining either locations and/or discriminations equal across ages, sexes, and/or twins are reported. The best fitting model (see Table 2) was the original unconstrained model (Model 1b) in which substance locations and

discriminations were estimated independently for each age and sex group but were constrained equal across twins (i.e., there were no birth-order effects). The good fit indices resulting from this model (CFI=0.99, TLI=0.99, RMSEA=0.068) support the use of a single-factor model. This resulted in six (3 ages $\times$ 2 sexes) sets of substance IRT parameters (locations and discriminations) being estimated.

3.1 Substance-level effects

Table 3 reports location and discrimination parameter estimates from the best-fitting IRT model. Substance parameters were compared:

- A. against different substances within each age-by-sex group,
- B. across ages within the same sex for each substance, and
- C. between sexes within the same age group for each substance.

Due to the large number of comparisons calculated ($N=210$), an alpha level of 0.001 was used for all significance testing. Figure 1 contains graphical plots derived from these parameter estimates. Looking across various substances in Table 3 and Figure 1, the substances maintained a reasonably consistent rank-ordering in terms of location. Alcohol tended to be at the low end, as indicated by its Item Response Functions (IRFs) and Item Information Functions (IIFs) being located farther left on the Figure (indicating that lower trait severity was required for likely endorsement of use). By contrast, the other controlled substances item indicated the greatest severity (as illustrated by its IRFs being located farthest to the right on the Z-score trait scale in Figure 1).

In terms of discrimination, uncontrolled substances consistently ranked as the least discriminating item regardless of age or sex. This is demonstrated by the shallow slopes of its IRFs and nearly flat IIFs in Figure 1. Thus, the uncontrolled substances item provides less information, while the other substances (those items with greater discriminations, steeper IRF slopes, and higher IIF peaks) provide more information over much narrower trait level ranges. For example, marijuana and tobacco, which rank as the most discriminating items in Table 3 at ages 14 and 17 (with the possible exception of the alcohol item for 17-year-old males), clearly have IIFs with the highest peaks and narrowest ranges at those ages in Figure 1.

3.1.1 Age effects on substance locations—Tests for statistical significance in Table 3 show a lack of parameter differences across substances at age 11. This is not surprising, given the low endorsement rates in this age group, which resulted in large standard errors on location and discrimination estimates. At age 14, substances form two distinct clusters in terms of location. Tobacco and alcohol comprise the less severe group. Greater location parameter estimates and farther right placement of the IRFs for marijuana, other controlled substances, and uncontrolled substances indicate that individuals who used these substances by age 14 would be higher on the poly-substance use trait than those who report only alcohol and/or tobacco use. At age 17, tobacco and alcohol remain the least severe indicators of poly-substance use. The other substances are now more spread out along the underlying dimension, with marijuana being less severe than the other controlled substances item. Use of uncontrolled substances falls roughly between marijuana and other controlled substances in terms of location, but it provides relatively little information (i.e., having a notably lower discrimination value when compared with marijuana and other controlled substances).

3.1.2 Age effects on substance discriminations—In Figure 1, the shallow slopes of the IRFs and low peaks of the IIFs at age 11 demonstrate the lack of discrimination (and subsequently, information) in this age group. Table 3 shows that standard errors on the greatest discrimination parameter estimates (i.e., tobacco in males and marijuana and other controlled

substances in females) resulted in confidence intervals that included zero (indicating that information provided was not significant) at this age. This overall reduction in discrimination and subsequent information would ultimately result in less reliable trait level estimates for individuals being evaluated with this measure in early adolescence.

3.1.3 Sex effects on substance locations and discriminations—No significant substance-level sex effects were observed in discriminations (see Table 3), nor were any consistent trends apparent. Specific substance locations reported in Table 3 also did not differ significantly between males and females, with the exception of tobacco at age 14 having a greater (more severe) location for females than males. However, Figure 1 illustrates a general trend for all substances to be more severe (i.e. their IRF midpoints and IIF peaks were located farther right) for females than males across ages. This means that, within an age group, a female must have a higher trait level on the underlying dimension of poly-substance use to endorse having used the same substances as a male. Because the sex difference trend in severity is consistent across substances, it may be thought of as impacting the underlying dimension, rather than acting in a specific way on distinct substances. Although there are not significant differences at the level of specific substances, equating parameters across sex diminished model fit, as shown in Table 2, suggesting a broader generalized influence of sex on poly-substance use.

3.2 Trait-level effects

Within each age-by-sex group, the IIFs in Figure 1 are summed together to form the Test Information Curves (TICs), shown in Figure 2. From the TICs, we are able to calculate the Standard Error of Measurement (SEM) for any given trait level, also shown in Figure 2. At age 11, the measure of diversity of substances used provides very little information, as evidenced by the relatively low height of the TICs at this age at low to mid trait levels, and the high SEM at trait levels less than two standard deviations above the mean. More information is provided at ages 14 and 17, although at these ages the measure appears to be estimating latent trait levels from the mean to two standard deviations above the mean (at age 14) or within one standard deviation of the mean (at age 17) relatively well. Less information is provided at more extreme trait levels, where the SEM is more substantial. As a result, we would expect trait level estimates for individuals outside of the mid-level trait range to be relatively less reliable. The measure of substances used provides adequate information for interpretation only beginning in mid-adolescence for those individuals who fall at a mid-level on the trait of poly-substance use.

3.2.1 Age effects on test information—Maximum information was provided at decreasing trait levels as age increased. This can be seen in Figure 2, where the TIC peaks are located farther to the left on the Z-score scale as age increases. As age increases, endorsement rates across substances also increase, making substance use relatively more normative and moving the TIC toward a middle level of poly-substance use. This suggests that age effects are well conceptualized at the level of the underlying poly-substance use trait.

3.2.2 Sex effects on test information—Figure 2 does not show substantial consistent sex differences in the TICs at each age, though the test information appears to span a slightly broader range of the underlying dimension of poly-substance use involvement for males than for females and provides peak information at slightly higher trait levels for females than for males. While there was limited evidence of item-level sex differences, the parameterization of the dimension as a whole differed slightly between sexes, as indicated by the fit of the model worsening when either location or discrimination parameters were constrained equal across sexes (see Table 2). As such, individual trait estimates resulting from the measure of substances used should still be estimated in a sex-specific context.

4. Discussion

Previous studies of prevalence and psychometric properties of substance use primarily focus on individual substances, treating each as distinct (e.g. Kahler et al., 2004; Kashdan et al., 2005; Krueger et al., 2004; Saha et al., 2006; Wallace et al., 2003). However, use of different substances is highly inter-correlated, as are the genetic and environmental contributions to the use of specific substances (e.g. Hall & Lynskey, 2005; Kendler et al., 2003). It is therefore likely that use of multiple substances forms a coherent dimension of overall poly-substance involvement. The application of multigroup IRT methodology allowed us to investigate individual substances in terms of how they relate to the dimension of poly-substance involvement, as well as estimating how age and sex effects operate at the level of the underlying dimension.

The present sample of Minnesota twins is not as diverse as the US population, and so these results may not be fully generalizable (e.g., the prevalence rates and relationships among substances may differ in other populations, especially where access to certain substances differs). Future research may address this issue through replication in a large national survey. In addition, to ensure that our data conformed to IRT model assumptions, we dichotomized use of each substance and clustered less frequently endorsed substances (i.e., other controlled substances and uncontrolled substances). However, this was a longitudinal study, which allows for greater interpretability of developmental effects. With these considerations in mind, we turn now to describe our findings in terms of the structure of poly-substance involvement, how development and sex affect that dimension, and the strength with which individual substances relate to the dimension of poly-substance involvement.

4.1 Structure of poly-substance involvement

The present application of multigroup IRT modeling to diversity of substances used allowed us to examine both the structure of poly-substance involvement as well as how age and sex impact poly-substance use at the level of the underlying dimension. Model fit indices supported a single dimension of poly-substance involvement during adolescence. This extends previous findings regarding adult poly-substance involvement (Kirisici et al., 2002) to the age range when substance use develops. Moreover, the clustering of substance locations in a relatively narrow range of trait levels (see Figure 1) indicates that diversity of substances used generally provides information about involvement with multiple substances. The largely non-significant differences in substance discriminations (see Table 3) demonstrated that all substances provided similar amounts of information on the underlying dimension (with the exception of uncontrolled substances; i.e., over-the-counter medications and inhalants; which were particularly uninformative).

4.1.1 Developmental effects on poly-substance involvement—While prevalence of use of individual substances displays consistent effects of age and sex (with use increasing with age and being greater in males than in females, e.g. see Table 1 and Derringer et al., 2008;Wallace et al., 2003), these factors impact substance use at the level of an underlying dimension rather than in an entirely substance-specific way. This was indicated by model fit worsening when parameters were constrained to be equal across either age or sex (see Table 2) and by age- and sex-related trends in estimated parameters generalizing across substances (see Table 3). When examining developmental effects on individual substances, location (the level of the trait) tended to decrease as age increased, indicating that an older person expressing the same degree of poly-substance involvement as a younger person possesses less of the trait. This trend can be observed functioning at the level of the overall poly-substance dimension in the peaks of the TICs (see Figure 2), which moved toward a more central trait level as age increased. This shows that diversity of substances used provides information on lower trait

levels as age increases, regardless of the specific substance or respondent sex (i.e., with increasing age, substance involvement becomes more normative). Significant information was obtained from diversity of substances used in both males and females at ages 14 and 17, indicating that even a simple measure of substance use does a reasonable job of capturing information on substance involvement throughout mid- to late-adolescence, so long as it includes multiple substances.

A distinct lack of information on poly-substance use was conveyed by diversity of substances used in 11-year-olds (see Figure 2). Essentially, age 11 is too early to be able to reliably pinpoint an individual's overall level of substance involvement. These substantial age-related differences in measure reliability are important to keep in mind, as studies of adolescent substance use tend to collapse across broad age bands (e.g. Maes et al., 1999; Rhee et al., 2003).

4.1.2 Sex effects on poly-substance involvement—While developmental effects are clearly observable in the TICs, the effect of sex on substance parameters appears more subtle at the level of the whole dimension (see Figure 2), with information peaks being located at slightly higher trait levels in females than in males. This means that a female endorsing the same substance use pattern as a male is displaying a slightly greater severity level of poly-substance involvement. This is consistent with applications of IRT models to adult poly-substance involvement (Kirisci et al., 2002) and substance disorder severity (Kirisci et al., 2006), which also indicated greater severity in females than in males who endorse using or meet disorder criteria for the same substance(s). The current study extended these findings to show that sex differences in the poly-substance involvement dimension emerge early and remain constant throughout adolescence.

4.2 Conclusions

Multigroup IRT modeling clearly illustrates differences in poly-substance use between ages and sexes that are well conceptualized as affecting a single, continuous dimension. Though diversity of substances used does not efficiently estimate specific latent trait levels across the broad dimension of poly-substance use involvement (e.g. the inclusion of frequency items could potentially better capture the high-end of the use severity dimension), it would provide a reasonable estimation of latent trait levels for those who fall at a mid-level of poly-substance use involvement, starting in mid-adolescence.

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Figure 1.

Item Response and Information Functions for each substance resulting from the best-fit model (Table 2, model 1, unconstrained except across twins) parameterization, separated by age and sex. The x-axis represents location, or the level of the trait in Z-score units. The y-axis associated with the Item Response Functions is the probability of endorsing use of a given substance or class at any given trait level.

Figure 2.

Test Information (black line) and Standard Error (grey line) Curves (plotted on a scale ranging from zero to six) resulting from the best-fit model (Table 2, model 1, unconstrained except across twins) parameterization, separated by age and sex. Test Information is the sum of the Item Information Functions (from Figure 1). The x-axis represents location, or the level of the trait in Z-score units.

Table 1

Endorsement Rates by Age, Sex, and Twin

First-born twins Substance/Class	11-year-olds (n=337)		14-year-olds (n=326)		17-year-olds (n=252)	
	Females	Males (n=356)	Females	Males (n=307)	Females	Males (n=246)
Alcohol	8.1%	16.9%	40.8%	48.2%	72.6%	75.6%
Tobacco	2.1%	5.1%	28.0%	39.9%	57.1%	68.7%
Marijuana	0.3%	1.1%	10.1%	14.0%	31.3%	39.0%
Other controlled substances [*]	0.3%	2.0%	5.8%	4.2%	10.7%	16.7%
Uncontrolled substances ^{**}	13.4%	24.3%	29.0%	30.9%	34.5%	30.1%

Second-born twins Substance/Class	11-year-olds (n=339)		14-year-olds (n=322)		17-year-olds (n=247)	
	Females	Males (n=354)	Females	Males (n=301)	Females	Males (n=247)
Alcohol	3.0%	17.4%	43.5%	54.3%	73.4%	76.1%
Tobacco	1.8%	6.1%	31.7%	47.2%	56.0%	74.9%
Marijuana	0.3%	0.6%	12.1%	15.9%	37.3%	47.0%
Other controlled substances [*]	0.6%	1.7%	5.0%	6.0%	9.9%	19.9%
Uncontrolled substances ^{**}	12.2%	24.5%	26.4%	29.4%	31.7%	33.6%

^{*} includes stimulants, tranquilizers, Quaaludes/downers, cocaine, psychedelics, and opiates^{**} includes over-the-counter medications and inhalants

Table 2

Questions and Answers About How Well Each Model Fits the Raw Data

Model	Question	Answer	How does the model fit?				
			χ^2	df	CFI	TLI	RMSEA
1	a. How does the unconstrained model fit?		170.7	44	0.98	0.97	0.10
	b. Can the twins be equated?	Yes	177.5	74	0.99	0.99	0.07
	Can we constrain...						
	item discriminations...						
2	a. across sexes?	No	239.7	59	0.98	0.97	0.10
	b. ...and twins?	No	259.1	83	0.98	0.98	0.08
3	a. across ages?	No	277.7	66	0.97	0.97	0.10
	b. ...and twins?	No	315.3	86	0.97	0.97	0.09
4	a. across sexes and ages?	No	324.6	71	0.97	0.96	0.11
	b. ...and twins?	No	355.9	89	0.96	0.97	0.10
	item locations...						
5	a. across sexes?	No	304.4	62	0.97	0.96	0.11
	b. ...and twins?	No	291.3	83	0.97	0.97	0.09
6	a. across ages?	No	2118.7	70	0.72	0.70	0.31
	b. ...and twins?	No	1703.4	87	0.78	0.81	0.25
7	a. across sexes and ages?	No	2083.2	76	0.73	0.73	0.30
	b. ...and twins?	No	1722.1	90	0.78	0.81	0.25
	item discriminations and locations...						
8	a. across sexes?	No	355.6	76	0.96	0.96	0.11
	b. ...and twins?	No	368.7	92	0.96	0.97	0.10
9	a. across ages?	No	1746.6	87	0.77	0.80	0.25
	b. ...and twins?	No	1722.6	97	0.78	0.83	0.24
10	a. across sexes and ages?	No	1745.9	97	0.78	0.82	0.24
	b. ...and twins?	No	1754.2	102	0.78	0.83	0.23

Table 3

Parameter Estimates from the Best Fitting Model (#1) – 99.9% Confidence Intervals are Shown in Parentheses

Age	Males		Females	
Substance/Class	Location	Discrimination	Location	Discrimination
11-year-olds				
Alcohol	1.9 (1.0,2.7)	0.6 (0.2,0.9)	2.4 (2.1,2.8)	0.8 (0.6,1.1)
Tobacco	1.7 (0.9,2.5)	2.5 (–5.1,10.1)	2.9 (2.5,3.3)	1.0 (0.6,1.4)
Marijuana	4.5 (1.6,7.4)	0.6 (0.1,1.1)	2.9 (1.8,4.0)	2.8 (–0.8,6.5)
Other Controlled*	2.6 (1.2,4.0)	1.3 (–0.6,3.2)	2.7 (1.8,3.7)	3.1 (–1.0,7.1)
Uncontrolled**	2.8 (–0.8,6.3)	0.3 (–0.1,0.6)	3.0 (2.4,3.7)	0.4 (0.3,0.5) ^{ab}
14-year-olds				
Alcohol	0.0 (–0.2,0.2) ^d	1.5 (0.9,2.1)	0.2 (0.0,0.4) ^d	1.4 (0.8,2.0)
Tobacco	0.2 (0.0,0.4) ^d	2.4 (0.7,4.1)	0.6 (0.4,0.8) ^{df}	2.9 (0.0,5.8)
Marijuana	1.1 (0.9,1.4) ^{abd}	2.2 (0.4,4.0)	1.3 (1.0,1.5) ^{abd}	3.5 (–2.0,9.0)
Other Controlled*	1.9 (1.3,2.5) ^{ab}	1.7 (0.1,3.3)	2.1 (1.4,2.8) ^{ab}	1.2 (0.4,2.0)
Uncontrolled**	1.3 (0.5,2.0) ^{ab}	0.4 (0.2,0.7) ^a	1.1 (0.6,1.6) ^{ad}	0.6 (0.3,0.9)
17-year-olds				
Alcohol	–0.8 (–1.0, –0.5) ^{de}	2.2 (0.5,3.9)	–0.8 (–1.1, –0.5) ^{de}	1.3 (0.7,1.9)
Tobacco	–0.6 (–0.9, –0.4) ^{de}	2.1 (0.7,3.5)	–0.2 (–0.4,0.0) ^{ade}	2.6 (0.3,4.9)
Marijuana	0.2 (0.0,0.4) ^{abde}	2.2 (0.7,3.7)	0.4 (0.2,0.7) ^{abde}	2.3 (0.6,4.0)
Other Controlled*	1.1 (0.7,1.5) ^{abc}	1.5 (0.5,2.4)	1.9 (1.1,2.6) ^{abc}	0.9 (0.4,1.5)
Uncontrolled**	1.3 (0.4,2.2) ^{ab}	0.4 (0.1,0.6) ^{bc}	1.3 (0.3,2.2) ^{abd}	0.4 (0.1,0.6) ^{ac}

Note. Significance tests were based on confidence interval comparisons. No significant differences between uncontrolled and other controlled substances were observed in discriminations or locations

* includes stimulants, tranquilizers, Quaaludes/downers, cocaine, psychedelics, and opiates

** includes over-the-counter medications and inhalants

^a differs from alcohol (p<.001)

^b differs from tobacco (p<.001)

^c differs from marijuana (p<.001)

^d differs from same-sex 11-year-olds (p<.001)

^e differs from same-sex 14-year-olds (p<.001)

^f differs from same-age males (p<.001)