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A FRAMEWORK TO EXAMINE GATEWAY RELATIONS IN DRUG USE: A N APPLICATION OF LATENT TRANSITION ANALYSIS

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Abstract

A progressive and hierarchical sequence of drug use suggests that a sequence of stages of drug use can describe the order by which adolescents try drugs. We propose an operational definition to test gateway relations by providing a framework with the aim of describing a set of conditions to guide the evaluation of whether a drug serves as a gateway for another drug. We used data from the National Longitudinal Study of Adolescent Health to demonstrate how using latent transition analysis we can estimate the odds of using a drug at a later time conditional on having used a gateway drug at an earlier time. We provide three empirical demonstrations for testing the gateway relations using a national and longitudinal data of adolescents (e.g., gateway relation between cigarettes and marijuana, alcohol and marijuana, and alcohol and cigarettes).

Introduction

Despite slight decreases in alcohol and tobacco use in recent years, alcohol and tobacco use continues to be a significant public health concern among adolescents (Johnston, O'Malley, Bachman, & Schulenberg, 2009). According to the Monitoring the Future Study, 58.3% of tenth graders have tried alcohol, 31.7% have tried tobacco, and 29.9% have tried marijuana (Johnston et al., 2009). Similarly, according to the Youth Behavior Risk Survey, 74.7% of high school students have ever tried alcohol, 48.8% have tried cigarettes, and 36.9% marijuana (Eaton et al., 2008). Literature concerning the etiology of drug use among youth suggests that legal drugs (e.g., alcohol and tobacco) serve as gateway drugs for illicit drug use. The gateway hypothesis of drug use has been defined as the notion of a progressive and hierarchical sequence of stages of drug use, suggesting an ordered progression of drug use involvement (Kandel, 1975; Kandel, 2002; Kandel, Yamaguchi, & Cousino Klein, 2006). According to this hypothesis, drug use involvement can be described by a sequence depicting the order by which adolescents try drugs; and the most common sequence starts with legal drugs (either alcohol or cigarettes), which are believed to increase the risk for trying illegal and harder drugs, such as marijuana, cocaine, and heroin.

Kandel provided the first attempt to systematically review what was known about the gateway hypothesis (Kandel, 2002). Specifically, Kandel and Jessor (2002) used three interrelated propositions to summarize current knowledge on the gateway hypothesis (Kandel & Jessor, 2002). First, the sequencing proposition suggests that drug use involvement includes “trying different classes or categories of drugs in an ordered fashion” (Kandel & Jessor, 2002, p. 365). Empirical evidence suggests that the drug use sequence

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typically starts with alcohol or cigarettes, followed by drunkenness, marijuana, and harder drugs (Collins, 2002; Fergusson, Boden, & Horwood, 2006; Hawkins, Hill, Guo, & Battin-Pearson, 2002; Kandel, 2002; Kandel & Yamaguchi, 2002). Second, the association proposition suggests that the “use of certain drugs is associated with increased risk for other more advanced drugs” (p. 366). Etiological, prevention and intervention studies have provided strong support for this proposition; therefore, many prevention efforts have targeted the reduction of initiation of gateway drugs based on the association proposition by arguing that preventing initiation of legal drugs reduces the likelihood of initiation of other illegal drugs (Botvin, Griffin, Diaz, & Ifil-Williams, 2001; Bretteville-Jensen, Melberg, & Jones, 2008; Cleveland & Wiebe, 2008; Degenhardt et al., 2009; Fergusson, et al., 2006; Lessem et al., 2006; Martin, 2003; Rebellion & Van Gundy, 2006; Wagner & Anthony, 2001).

A gap in the literature is that although the term gateway hypothesis is well known, there is no widespread agreement about exactly how to operationalize the gateway hypothesis applied to the study of drug use involvement among adolescents. In the current study, we integrate the frameworks of Kandel and Jessor (2002) and Collins (2002) to provide an operational definition of the gateway hypothesis that will allow the examination of whether or not a gateway relation exists between two drugs using empirical data. We develop this framework with the aim of describing a set of conditions to guide the evaluation of whether a drug serves as a gateway for another drug. In sum, the present study will (1) propose an operational definition of the gateway hypothesis for the progression of drug use, and (2) demonstrate its use in a longitudinal study of adolescent drug use onset using latent transition analysis.

An Operationalization Of The Gateway Hypothesis

Kandel and Jessor (2002) provided a schema for organizing the literature on the gateway hypothesis. In the current study, we integrate the first two propositions suggested by Kandel & Jessor (2002) (i.e., sequencing and association proposition) with the methodological operationalization of the gateway hypothesis as outlined by Collins (2002). Collins (2002) called for an explicit probability-based definition of the gateway hypothesis using latent transition analysis to estimate the relevant probabilities. She argued that there is a gateway relation between drug A and drug B if:

1. There is a clear order whereby drug A is tried before drug B.
2. The probability of trying drug B is greater for those who have tried drug A when compared to those who have not tried drug A.

The first condition established an order in which the drugs are tried, an important, but not sufficient condition for a gateway relation between two drugs. The second condition tested whether use of one drug is associated with increased risk for use of the other drug. According to this definition, both of these conditions must be met in order for a gateway relation to exist between drugs.

In the current study, we propose an operational definition of the gateway hypothesis that like Collins (2002) is probability-based, and focuses on the risk for using drug B at a later time (conditional on use of a gateway drug at an earlier time). There is *no gateway relation* if: drug A precedes the use of drug B, but use of drug A at an earlier time does not increase the risk for use of drug B at a later time (i.e., odds equal to 1). To evaluate whether one drug increases the risk for another drug, we use latent transition analysis (LTA) to a longitudinal model of drug use in order to estimate the odds of using drug B after having tried drug A. In the next section of this manuscript, we (a) describe LTA (as a statistical tool to test gateway relations) and (b) introduce three empirical demonstrations for testing the gateway relations

using a national sample data of adolescents from a longitudinal study. In the first example, we test for a gateway relation between cigarettes and marijuana; the second tests for a gateway relation between alcohol and marijuana; and the third tests for a gateway relation between alcohol and cigarettes.

Methods

Participants

To illustrate how to test for gateway relations using longitudinal data, we used data from the National Longitudinal Study of Adolescent Health (Add Health; Harris, 2009). We used data from one cohort of adolescents in tenth ($n=2019$) grade who were first interviewed between April and December 1995; and the same subjects were interviewed again between April and August 1996. We included data from wave 1 and wave 2 because it captures the adolescence developmental period in which the initiation of drugs typically occurs; recent data from Add Health included measures among young adults. For the current study, adolescents were age 15.7 years old ($sd=.46$) at wave 1 (53.7% females and 46.3% males). Youth were predominantly White (72.2%); and other ethnic groups were also included (16.8% African American/Black and 13.6% self-identified as Latino/Hispanic ethnic background).

Measures

To measure an individual's level of drug use, five items were used at each wave. Table 1 reports the frequency distribution and percentage of drug use at each time. Responses on these items were coded "never used" and used "once or more." Three items were used to measure alcohol and drunkenness at each time. Alcohol use was assessed with one item: During the past 12 months, on how many days did you drink alcohol? Drunkenness were measured with two additional items: Over the past 12 months, on how many days did you drink five or more drinks in a row? and Over the past 12 months, on how many days have you gotten drunk or 'very, very high' on alcohol? One item was used to measure cigarette smoking at each wave: During the past 30 days, on how many days did you smoke cigarettes? One item was used to measure marijuana at each wave: During the past 30 days, how many times did you use marijuana? In the Add Health study, the time frame for reporting cigarette and marijuana use was the last 30 days, whereas alcohol and drunkenness were assessed during the last 12 months. The use of other illicit drugs (i.e., recent use of cocaine) was not included because of very low sample size ($n=24$ at time 1 and $n=18$ at time 2).

Analytical Strategy

To evaluate whether a gateway relation existed between two drugs, three analytical steps were followed:

1. Fit a latent transition model.
2. Identify population at risk.
3. Calculate the odds ratio (*OR*) to evaluate gateway relations.

This procedure was followed to examine the gateway relation in both directions, that is, drug A to drug B and then drug B to drug A. We describe each step below. All models were fit using proc latent transition analysis (LTA) (Lanza, Lemmon, Schäfer, & Collins, 2008), available for download at <http://methodology.psu.edu>.

Step 1: Fita Latent Transition Model

LTA provides a way of testing for the probability-based definitions of the gateway relations discussed in the previous section. LTA, an extension of latent class analysis to longitudinal data, takes a categorical approach to the latent variable (in this case drug use behaviors), and expresses change in the form of transition probabilities (Collins & Lanza, 2010; Collins & Wugalter, 1992; Lanza, et al., 2008). LTA is an ideal framework for examining the gateway hypothesis because it accommodates for examining measurement error in drug use behavior items, and it provides a means of estimating and testing stage-sequential models with longitudinal data. The model has been used extensively to estimate stage-sequential models of drug use behavior over time (e.g., Collins, 2002; Guo, Collins, Hill, & Hawkins, 2000; Maldonado-Molina et al., 2007; Patrick et al., 2009).

First, to identify a model that best represented the heterogeneity in patterns of drug use, we relied on several model fit information criteria (i.e., Bayesian Information Criteria (Raftery, 1986) and Akaike Information Criterion (Akaike, 1973)). Based on these criteria, we compared several competing models (from two to eight stages of drug use). Second, to interpret each drug-use stage in the selected model, we first examined the probability of responding “yes” (or “no”) to each item conditional on latent stage membership. These parameters are important because they are used to determine which stages of drug use are characterized by a high probability of endorsing each drug item, and form the basis on which stages of drug use are labeled. For instance, a stage characterized by low probability of responding “yes” to the alcohol and drunkenness items but high probability of responding “yes” to cigarette and marijuana items could be labeled the “cigarette and marijuana stage.” Third, we examined the probability of membership in each drug use stage. For instance, we estimated the probability of membership in the “no use” stage, and compared it with the probability of membership in the “alcohol only” stage or the “alcohol, cigarettes, and marijuana” stage. These parameters are very important when testing for gateway relations because they reflect the prevalence of each drug in combination with other drugs. In addition, based on these stage prevalences, the overall probability of using a particular drug can be calculated by including drug-use stages that include that drug. Also of importance in a study of gateway relations is any drug use stages that do not emerge in the LTA model. For instance, we would not expect to see a stage characterized by marijuana use but not use of one of more legal substances (e.g., alcohol and cigarettes). Finally, we examined the probability of drug-use stage membership at time 2 conditional on stage membership at time 1. These parameters are a key component when testing for gateway relations between drugs because they reflect initiation of drug use over time conditional to prior drug use. For instance, for two times of measurement, a transition probability might represent the probability of membership in the “alcohol and cigarettes” stage at time 2 conditional on membership in the “alcohol only” stage at time 1, revealing important information about sequencing of the drug use and providing essential elements for estimating *OR*.

Step 2: Identify Population at Risk

To define the population at risk for initiating drug B, we estimated the proportion of the population that have not used drug B at time 1. For instance, to estimate whether a gateway relation exists between cigarettes and marijuana, we first identified the population of those who are not using marijuana at time 1. These individuals may or may not report cigarette use at time 1; of interest is the increased risk for later marijuana use that cigarette use poses.

Among the population at risk (e.g., individuals who are not reporting drug B at time 1), we estimated the following four probabilities:

1. Probability of using drug B at time 2 conditional on having used drug A at time 1 (quantity *a*)

2. Probability of *not* using drug B at time 2 conditional on having used drug A at time 1 (*b*)
3. Probability of using drug B at time 2 conditional on *not* having used drug A at time 1 (*c*)
4. Probability *not* using drug B at time 2 conditional on *not* having used drug A at time 1 (*d*)

These estimates correspond to the 2×2 table presented below.

		Drug B at Time 2	
		Yes	No
Drug A at Time 1	Yes	<i>a</i>	<i>b</i>
	No	<i>c</i>	<i>d</i>

Step 3: Test for Gateway Relations Using Longitudinal Data

To examine whether drug A serves as a gateway for drug B, we used longitudinal data to estimate the risk of using drug B at time 2, a later time conditional on having used drug A at

an earlier time (e.g., time 1), where OR is equal to $\frac{a/b}{c/d}$. If the odds ratio is equal to 1, there is no gateway relation because there is no increased risk of using drug B at time 2 conditional on having used drug A at time 1 ($OR=1$). There is a gateway relation if the odds ratio is greater than 1, indicating that there is increased risk of using drug B at time 2 conditional on having used drug A at time 1.

In order to conduct hypothesis testing, we estimated an LTA (as identified in step 1), then generated 1000 bootstrap samples, estimated the LTA model for each dataset and combined estimates from these bootstrap samples (see Appendix A). Therefore, uncertainty in the estimates is reflected by combining results across 1000 generated datasets. Bootstrap is an appropriate method because the tests of gateway hypotheses require creating linear combinations of LTA parameter estimates. Because we do not have standard errors of these newly-created parameters, we need to use the bootstrap or a related procedure in order to conduct significance tests based on these linear combinations. Estimates to calculate gateway relations represent the combined estimates from 1000 bootstrap samples (see Appendix A for an illustration).

Results

Stages of Drug Use: Results from a Latent Transition Analysis Model

In step one of our analyses we found that a model with seven stages of drug use best represented the heterogeneity in patterns of drug use among adolescents. A 7-class model ($G^2=380.12$, $df=940$) provided the lowest AIC , and one of the lowest BIC s ($AIC=546.12$, $BIC=1011.78$) when compared with several competing models (see Table 2). Model selection indices suggested that the optimal model has between five stages (no use, A, C, AD, and ACDM) and seven stages. Upon careful consideration of these models, the seven-stage model was selected because it was more precise in depicting stages of drug use, including two additional stages (CM and ACD). Specifically, the five-stage model included: no use, A, C, AD, and ACDM; the six-stage model included: five stages described above + ACD; and the seven-stage model included: six stages + CM. These stages are consistent

with the literature and indicate that a group of adolescents try marijuana without the recent use of alcohol (i.e., CM), and there is a group of adolescents who engage in alcohol and smoking behaviors without the use of marijuana (i.e., ACD stage).

The probability of responding “yes” to each item conditional on membership in a drug use stage is shown in Table 3. Note that high (over .7) probabilities are shown in bold to facilitate interpretation. The prevalence at Time 1 and Time 2 for each drug use stage is also reported in Table 3. For instance, at time 1, approximately half of adolescents belong to the “No use” stage of recent drug use (44.9%), followed by “Alcohol Only” and “Alcohol, Cigarettes, Drunkenness, and Marijuana” users (15.8% and 14.7%, respectively), “Alcohol and Drunkenness” (11.3%), “Alcohol, Cigarettes, and Drunkenness” users (6.5%), “Cigarettes only” users (5.1%) and “Cigarettes and Marijuana” (1.8%) users.

Table 4 reports the prevalence in a drug use stage at Time 2 conditional on membership at Time 1 behavior (i.e., transition probabilities). For instance, 78.9% of adolescents were in the “No use” stage at Time 2 conditional on membership in the same drug use stage at Time 1. Similarly, among “Alcohol Only” users at time 1, 43% remained in this stage one year later (time 2), while 14.3% experienced drunkenness, and 12.8% experienced drunkenness and smoking behaviors. Among “Cigarettes only” users at time 1, 16.3% advanced to experienced drunkenness, and 14.0% belong to the advanced stage of drug use (describing alcohol, smoking, drunkenness, and marijuana behaviors).

Example 1: Gateway Relation Between Cigarettes and Marijuana

To estimate whether cigarettes serve as a gateway drug for marijuana, we calculated the population at risk (i.e., individuals who did not report marijuana use at time 1). We combined estimates using the bootstrap method, and result indicated that 79.2% of adolescents did not report marijuana use at time 1 (average of membership in stages of drug use that did not include marijuana; i.e., No, A, C, AD, and ACD stages). Next, we calculated four quantities (see Table 5, Panel A). To calculate quantity *a* (e.g. cigarettes users at time 1 and marijuana users at time 2), we calculated the proportion of adolescents who were in stages involving cigarettes use (i.e., C and ACD) and who transition to stages, including marijuana use (i.e., CM or ACDM). To calculate quantity *b* (the proportion of adolescents who were cigarettes users at time 1 and who were *not* exposed to marijuana at time 2), we estimated the proportion of adolescents who were in the C and ACD stages at time 1 and in the No use, A, C, AD, or ACD stage at time 2. To calculate quantity *c* (adolescents *not* exposed to cigarettes at time 1 but were exposed to marijuana at time 2), we estimated the proportion of adolescents who were in the No use, A, and AD stages and transition to the CM or ACDM stages at time 2. Finally, to calculate quantity *d* (adolescents *not* exposed to cigarettes at time 1 and *not* exposed to marijuana at time 2), we estimated the proportion of those who were in the No, A, and AD stages at time 1 and who were in the No, A, C, AD, or ACD stage at time 2 (see Appendix B for an illustration on how these four quantities were estimated). Results indicate that a gateway relation might exist ($OR=1.91$; $p=.07$), indicating a trend of increased risk of recent marijuana use (drug B) at time 2 among adolescents who reported cigarette use (drug A) at time 1, compared to those who did not report cigarette use at time 1.

To evaluate the role of marijuana as a gateway drug for cigarettes, we calculated the population at risk (those who reported not using cigarettes at time 1; 89.9%); however, there was not a stage of drug use that included marijuana at time 1 without the use of cigarettes. For instance, two stages of drug use included marijuana users (i.e., CM and ACDM); however, there was no “Marijuana only” or “Alcohol and Marijuana” stage to calculate the prevalence of those exposed to marijuana at time 1 (among the population at risk; non-smokers at time 1). Therefore, the odds of recent cigarette use at time 2 conditional on time

1 marijuana use were not estimable because among the population at risk the probability of using cigarettes at time 2 conditional on having used marijuana at time 1 was zero.

Example 2: Gateway Relation between Alcohol and Marijuana

To estimate the role of alcohol as a gateway drug for marijuana, we identified the population at risk (i.e., the proportion of the population who were not using marijuana at time 1) (79.2%) and then calculated the four quantities needed for the odds ratio (see Table 5, Panel B). The odds ratio of recent marijuana use at time 2 conditional on time 1 recent alcohol use was 1.75, suggesting that there is increased risk of recent marijuana use (drug B) by time 2 conditional on having recently used alcohol (drug A) at time 1 ($p=.04$). Therefore, we found evidence that alcohol serves as a gateway drug for marijuana.

To estimate the role of marijuana as a gateway drug for alcohol, we estimated the population at risk (i.e., the proportion of the population who were not using alcohol at time 1, 86.4%), and then calculated four quantities (see Table 5, Panel B). Results indicated that the risk for using alcohol at time 2 was higher among the unexposed population (.29) when compared to the exposed population (.20), suggesting that a higher proportion of the population at risk who were not exposed to marijuana were alcohol users at time 2. Therefore, results indicate that marijuana did not serve as a gateway drug for alcohol because it was not associated with increased risk of recent alcohol use (drug B) by time 2 conditional on having recently used marijuana (drug A) at time 1 (see Appendix C for an illustration on how these quantities were estimated).

Example 3: Gateway Relation between Alcohol and Cigarettes

Results indicated that a gateway relation exist between alcohol and cigarettes because use of alcohol at time 1 was associated with increased risk for cigarette use at time 2 ($OR= 1.24$; $p=.002$). Therefore, we found support that recent use of alcohol serve as a gateway drug for recent cigarette use. We also tested the role of cigarettes as a gateway drug for alcohol and results suggest that a gateway relation does not exist between use of cigarettes time 1 and alcohol use at time 2, because the risk for alcohol use at time 2 was higher among the unexposed population (i.e., not cigarettes users, .325) when compared with the exposed (i.e., cigarette users, .163) population (see Appendix D for an illustration). Therefore, there is no evidence for increased risk for alcohol use at time 2 conditional on having used cigarettes at time 1.

Discussion

This study extends current literature on the gateway hypothesis by proposing a framework for examining the gateway hypothesis of drug use among adolescents. The present study integrated conceptual and methodological approaches to the study of the gateway hypothesis, as outlined by Kandel and Jessor (2002) and Collins (2002), and proposed an operational definition to test the gateway hypothesis. We proposed to test gateway relations by using longitudinal data to estimate the odds of using a drug at a later time conditional on use of the gateway drug at an earlier time. This framework was illustrated by examining whether a gateway relation exists between:

1. Cigarettes and marijuana
2. Alcohol and marijuana
3. Alcohol and cigarettes

Results indicated that both alcohol and cigarettes served as a gateway drug for marijuana, and alcohol also served as a gateway drug for cigarettes.

Previous studies examining the gateway hypothesis have reported inconsistent findings, mostly as the result of differences in the conceptualizations and operationalizations of the hypothesis (Kandel, 2002). Most of the work on the gateway hypothesis, including work from Kandel and colleagues, has been based on an approach that reflects a hierarchical and unidimensional order of use (Kandel, 2002). One limitation of these cross-sectional studies is that it prevents the examination of the temporal order by which drugs are initiated. Therefore, to evaluate gateway relations, the current study used longitudinal data to examine patterns of drug use among youth. By using longitudinal data, this study described the prospective nature of drug use involvement among adolescents by modeling the etiology of behavior as a series of stages of drug use. The current project also expanded the probability-based definition first proposed by Collins (2002) to guide the investigation of whether a gateway relation exists between drugs. Using the proposed framework for testing the gateway hypothesis can shed light on the strength of the association between gateway drugs.

The current study is consistent with previous studies that applied LTA to examine transitions in substance use behavior using data from the Add Health Study (e.g., Collins, 2002; Hyatt & Collins, 2000; Lanza & Collins, 2002); however, none of these studies has evaluated a recent substance use model. For instance, Lanza and Collins (2002) reported eight stages of lifetime drug use onset among adolescents. Hyatt and Collins (2002) and Collins (2002) also applied latent transition analysis to examine risk and protective factors associated with onset of substance use, and they also reported eight stages describing a lifetime model of drug use. The current study identified seven of these eight stages of drug use, with the exception of a stage describing recent use of alcohol and cigarettes without engaging in drunkenness behaviors. This may be expected due to the focus on recent use as opposed to lifetime use. As a result, the current study represents an application of LTA using a national representative study to examine patterns of recent substance use among adolescents.

The current study also used repeated assessments of recent use of each drug when examining the gateway hypothesis. Each item assessed whether adolescents had recently use each drug, including alcohol, cigarettes, drunkenness, and marijuana. An alternative approach would be to examine whether the dosage by which a drug is tried at time 1 is associated with increased risk for trying another drug. A model examining youth's engagement with large quantities of a drug and experiencing abuse and/or dependence would shed light on whether a large dose of one drug, as opposed to simply trying a drug, serves a gateway role for another drug.

By using the proposed operational definition of gateway relations, researchers can examine the relation between drug dose and other risk factors associated with adolescent problem behaviors. Indeed, the definitions of the gateway relations outlined in the current study can be applied to the study of association of any events, particularly to examine whether one event is a risk factor for a subsequent event. Using such a framework can extend the current definition of gateway relations beyond the examination of the gateway hypothesis of drug use among youth. It is also important to acknowledge that, in addition to dosage, the sampling of times of measurement (temporal design of the study) can influence the interpretation of gateway relations. This is an important consideration when drawing conclusions about the gateway hypothesis because the duration between observations will influence whether researchers can observe the transitions between initiations of each drug in a sequence. In the current study, there was a one-year period between measurements. It is possible that the spacing between observations was too far apart, and therefore, potential gateway relations between drugs might have been overlooked. For instance, if the initiation of two dmgs occurs very close in time (e.g., initiation of alcohol and cigarettes both occur within the same month) and the study design measures transitions between dmgs that occur over the course of a year, then the study risks overlooking the ordered sequence by which

these dmgs are initiated. On the other hand, if the spacing between observations was too close together (e.g. monthly measurements when transitions tend to occur much less frequently), then researchers risk overlooking important gateway relations. The significant gateway relations that were identified, however, suggest that the temporal design was reasonable for studying dmg use behavior in this population.

Several limitations of the current study are worth noting. First, this study only included one cohort of middle adolescents of the National Longitudinal Study of Adolescents Health. Future studies should examine patterns of dmg use involvement among youth at other stages of development, particularly early adolescence when initiation of drug use is most problematic (Brown, Miller, & Clayton, 2004; Griffin, Botvin, Epstein, Doyle, & Diaz, 2000; Henry, Slater, & Oetting, 2005; Tucker, Ellickson, Orlando, Martino, & Klein, 2005). It is possible that different gateway relations hold in younger and older cohorts. For instance, we examined patterns of dmg use behaviors among ninth and eleventh grade cohorts of Add Health and found a similar structure of recent dmg use. Such results would suggest prevention programs that could be targeted differentially to adolescents, depending on both their age and their level of dmg use at the time of intervention. Another limitation of the current study is that, although it uses a national representative dataset, this dataset was collected in 1995–1996. Therefore, current patterns of dmg use involvement might differ from those of a decade ago, as the availability of dmgs changes with restrictive policies, and with more aggressive efforts to limit youth's access to illegal dmgs, and the availability of new dmgs in the market. Future studies should compare how stages of recent dmg use (from current and previous studies) compare to more contemporary data. The current study provides a set of guidelines that will permit such a comparison. Importantly, the current study did not examine differential gateway relations by moderators such as gender or race/ethnic group. Such analyses are an important area of future study.

Despite its limitations, the current study extended the literature on the gateway hypothesis by proposing a general probability-based framework for evaluating and testing the gateway hypothesis of dmg use among adolescents. Future research is merited to examine factors that moderate gateway relations in this population and to evaluate gateway relations among other combinations of dmgs and in other populations. The proposed guidelines for examining the gateway hypothesis provide a general framework for testing gateway relations between drugs to better inform the prevention of advancement in drug use among adolescents.

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Appendix

Appendix A.

Steps to test for gateway relations using bootstrap datasets

Appendix

Appendix B. Gateway relation between cigarettes and marijuana

a =Exposed to cigarettes at time 1 and exposed to marijuana at time 2; b =Exposed to cigarettes at time 1 and *not* exposed to marijuana at time 2; c = *Not* exposed to cigarettes at time 1 and exposed to marijuana at time 2; d =*Not* exposed to cigarettes at time 1 and *not* exposed to marijuana at time 2.

Appendix C. Gateway relation between alcohol and marijuana

Figure C1. Alcohol as a gateway for marijuana use

a =Exposed to alcohol at time 1 and exposed to marijuana at time 2; b =Exposed to alcohol at time 1 and *not* exposed to marijuana at time 2; c = *Not* exposed to alcohol a time 1 and exposed to marijuana at time 2; d =*not* exposed to alcohol at time 1 and *not* exposed to marijuana at time 2.

Figure C2. Marijuana as a gateway for marijuana use

a =Exposed to marijuana at time 1 and exposed to alcohol at time 2; b =Exposed to marijuana at time 1 and *not* exposed to alcohol at time 2; c = *Not* exposed to marijuana a time 1 and exposed to alcohol at time 2; d =*Not* exposed to marijuana at time 1 and *not* exposed to alcohol at time 2.

Appendix D. Gateway relation between alcohol and cigarettes

Figure D1. Alcohol as a gateway for cigarettes use

a =Exposed to alcohol at time 1 and exposed to cigarettes at time 2; b =Exposed to alcohol at time 1 and *not* exposed to cigarettes at time 2; c = *Not* exposed to alcohol a time 1 and exposed to cigarettes at time 2; d =*Not* exposed to alcohol at time 1 and *not* exposed to cigarettes at time 2,

Figure D2. Cigarettes as a gateway for alcohol use

a =Exposed to cigarettes at time 1 and exposed to alcohol at time 2; b =Exposed to cigarettes at time 1 and *not* exposed to alcohol at time 2; c = *Not* exposed to cigarettes a time 1 and exposed to alcohol at time 2; d = *Not* exposed to cigarettes at time 1 and *not* exposed to alcohol at time 2.

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Table 1Frequency Distribution of Recent Drug Use of Each Categorized Item at Each Time of Measurement, *N*=2019

Item	Time 1		Time 2		
	<i>N</i>	%	<i>N</i>	%	
Alcohol ¹	Yes	1090	53.99	917	45.42
	No	923	45.72	844	41.82
	Missing	6	0.30	258	12.78
Cigarettes ²	Yes	597	29.57	622	30.81
	No	1409	20.26	1150	56.96
	Missing	13	0.64	247	12.24
5+ Drinks ¹	Yes	643	31.85	574	28.43
	No	1371	67.90	1193	59.09
	Missing	5	0.25	252	12.48
Drunk ¹	Yes	693	34.32	589	29.17
	No	1323	65.53	1179	58.40
	Missing	3	0.15	251	12.43
Marijuana ²	Yes	321	15.90	262	12.98
	No	1654	81.92	1477	73.16
	Missing	44	2.18	280	13.87

¹ Last 12 months.² Last 30 days

Table 2

Model Selection for Competing Models

Number of classes	G^2	df	BIC	AIC
2	1431.68	1010	1530.62	1431.68
3	1011.88	1000	1186.91	1057.88
4	620.11	988	886.47	690.11
5	499.99	974	872.90	597.99
6	419.82	958	914.49	549.82
7	380.12	940	1011.78	546.12
8	346.58	920	1130.44	552.58

Table 3

Item Response Probability of a “Yes” Conditional on Status Membership for Each Drug Use Item and Time 1 and 2 Prevalence in Stages of Drug Use

Stage	Item-response probability				Prevalence	
					Time 1	Time 2
	Alcohol	Cigarette	Drink	Drunk	Marijuana	%
No	0.078	0.012	0.000	0.000	0.007	.449
A	1.00	0.085	0.211	0.235	0.054	.158
C	0.281	1.00	0.000	0.000	0.000	.051
AD	1.00	0.153	0.901	0.981	0.178	.113
CM	0.381	0.835	0.000	0.000	1.00	.018
ACD	1.00	0.999	0.865	0.827	0.000	.065
ACDM	1.00	0.908	0.914	0.964	0.730	.147

No= No use; A= Alcohol only; C= Cigarettes only; AD= Alcohol and Drunkenness; CM= Cigarettes and Marijuana; ACD= Alcohol, Cigarettes, and Drunkenness; ACDM= Alcohol, Cigarettes, Drunkenness, and Marijuana. Estimates (.000) were estimated to be zero; no parameters were fixed. Estimates in bold represent high probability of endorsing the item. Parameters were constrained to be equal across time.

Table 4

Transition Probabilities: Probability of membership in Each Stage of Drug Use at Time 2 Conditional on Drug Use Membership at Time 1

Time 1 stage	Time 2 stage					
	No	A	C	AD	CM	ACD
No	.789	.077	.038	.046	.003	.028
A	.204	.430	.053	.143	.042	.128
C	.163	---	.475	---	.059	.163
AD	.154	.124	.066	.412	.034	.070
CM	.188	.004	.180	.120	.196	.130
ACD	.100	---	.200	---	---	.556
ACDM	.057	.032	.075	.087	.091	---

--- indicates that this conditional probability was estimated to zero (within rounding). No probabilities were fixed.

No= No use; A= Alcohol only; C= Cigarettes only; AD= Alcohol and Drunkenness; CM= Cigarettes and Marijuana; ACD= Alcohol, Cigarettes, and Drunkenness; ACDM= Alcohol, Cigarettes, Drunkenness, and Marijuana.

Table 5

Gateway Relations between (A) Cigarettes and Marijuana, (B) Alcohol and Marijuana, and (C) Alcohol and Cigarettes

Panel A: Cigarettes and Marijuana

Marijuana use at time 2				
		Yes	No	
Cigarettes at time 1	Yes	0.025	0.125	OR= 1.91
	No	0.061	0.581	

Panel B: Alcohol and Marijuana

Marijuana use at time 2				
		Yes	No	
Alcohol at time 1	Yes	0.033	0.182	OR= 1.75
	No	0.054	0.524	

Alcohol use at time 2				
		Yes	No	
Marijuana at time 1	Yes	0.014	0.058	OR= 0.58
	No	0.236	0.557	

Panel C: Alcohol and Smoking

Smoking at time 2				
		Yes	No	
Alcohol at time 1	Yes	0.100	0.145	OR= 1.22
	No	0.229	0.421	

Alcohol use at time 2				
		Yes	No	
Smoking at time 1	Yes	0.034	0.176	OR= 0.41
	No	0.209	0.443	

Increased risk: Among population at risk (those who were not marijuana users at time 1), the risk for using marijuana at time 2 was 1.91 times higher among those exposed to cigarettes at time 1 (.168) when compared to the unexposed population (.095).

Increased risk: Among population at risk (those who were not marijuana users at time 1), the risk for using marijuana at time 2 was 1.75 times higher among those exposed to alcohol (.152) at time 1 when compared to the unexposed population (.10).

Not increased risk: Among population at risk (those who were not alcohol users at time 1), the risk for using alcohol at time 2 was higher among non-marijuana users (.30) when compared with marijuana users at time 1 (.20).

Not increased risk: Among population at risk (those who were not cigarette users at time 1), the risk for using cigarettes at time 2 was higher among alcohol users (.40) when compared with non-alcohol users at time 1 (.37).

Not increased risk: Among population at risk (those who were not alcohol users at time 1), the risk for using alcohol at time 2 was higher among non-smokers (.33) when compared with smokers at time 1 (.16).