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Tobacco, Alcohol and Marijuana Use among First Year U.S. College Students: A time series analysis

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Abstract

The present study sought to evaluate the day-to-day patterns of tobacco, alcohol and marijuana use among first year college students in the U.S. Using 210 days of weekly time-line follow-back diary data collected in 2002–2003, the authors examined within-person patterns of use. The sample was 48% female and 90% Caucasian. Sixty eight percent of the participants were permanent residents of Indiana. Univariate time series analysis was employed to evaluate behavioral trends for each substance across the academic year and to determine the predictive value of day-to-day substance use. Some of the most common trends included higher levels of substance use at the beginning and/or end of the academic year. Use on any given day could be predicted best from the amount of corresponding substance use one day prior.

Conclusions—While universal intervention might best be focused in the earliest weeks on campus and at the end of the year when substance use is at its highest, the diversity of substance use trajectories suggests the need for more targeted approaches to intervention. Study limitations are noted.

Keywords

College student; Smoking; Tobacco; Alcohol; Marijuana; Trajectories; Time Series; Person-Centered; Autocorrelation

Tobacco, alcohol and marijuana are the most widely abused substances (SAMHSA, 2003). They have been linked to a myriad of both short and long-term consequences including accidental injury and death, impairment of interpersonal relationships, unemployment, and disease (USDHHS, 1998, 1999). Recent research has further documented surprisingly high smoking rates among U.S. college students with almost 30% having smoked within the past 30 days, and 43% of these smoking up to 10 cigarettes per day (Rigotti, Lee, & Wechsler, 2000). Similarly, rates of marijuana use have been on the rise in this population during the past decade. Percent of past 30-day and past-year marijuana use increased significantly between 1993 and 2001 from 13% to 17% and 23% to 30%, respectively (Mohler-Kuo, Lee, & Wechsler, 2003). Finally, while results from several national longitudinal databases suggest that, in high school, U.S. students that are college-bound have lower rates of heavy alcohol consumption compared to those who will not attend college, those who go on to college increase their alcohol consumption and actually surpass their non-college counterparts (O'Malley & Johnston, 2002).

Contemporary theories of substance initiation and experimental use have commonly focused on such primary influences as cognitive processes (e.g. beliefs about the consequences of use),

social learning processes (e.g. friendship selection) and individual characteristics (e.g. personality traits) (Petratis, Flay, & Miller, 1995). As the focus changes from initiation/experimentation to addiction, etiologic theory shifts toward a more central focus on the pharmacologic influences of the substance (Weiss & Koob, 2001). Notably, research that has formed the basis for theories of early vs. established patterns of use has traditionally used quite dissimilar study designs in terms of temporal resolution. That is, studies that have prospectively examined the onset and escalation of substance use within adolescence and young adulthood have commonly relied on longitudinal designs that capture only a few time-points at fairly long inter-assessment intervals (i.e. 12 months or longer) (Collins & Graham, 2002). In contrast, both human and animal work seeking to explain the process of addiction, has focused on more proximal assessments at both daily and within-day intervals (Donny, Bigelow, & Walsh, 2003; Donny et al., 2003).

The more proximal (i.e. day-to-day) influence of substance use among non-established users and the contribution of more distal factors on behavior patterns among established users have received relatively little attention. Further, in that previous research has relied heavily in linear regression techniques which elucidate population averages, resultant empirical findings have been demonstrated as least generalizable to those individuals exhibiting the largest deviations from the population mean (Labouvie, Pandina, & Johnson, 1991). In contrast, artificial intelligence and its theoretical underpinnings have been instrumental in documenting the nature of human behavior as non-linear, complex, dynamic, law driven and bounded by such contexts as time, place, gender and age (Buscema, Intraligi, & Bricolo, 1998). To date, our ability to explore such complexity has been limited by the use of traditional linear methods.

A statistical methodology particularly appropriate for evaluating the more naturalistic process of human behavior is time series analysis, a procedure aimed at gathering longitudinal data with a regular inter-assessment interval and a relatively large number of repeated observations across time (Velicer & Fava, 2003). There are two main goals of time series analysis: (1) identifying the nature of the phenomenon represented by the sequence of observations (i.e. evaluating the behavioral trend), and (2) forecasting or predicting future values of the behavior based on the most recent observation as well as observations more temporally removed (StatSoft, 2004). Previous research utilizing time series analysis to examine substance use patterns has most clearly demonstrated the value of the most proximal observations in predicting future behavior. That is, when considering either tobacco smoking (Velicer, Redding, Richmond, & Greeley, 1992) or alcohol use (Mundt, Searles, Perrine, & Helzer, 1995), consumption reported on any given day has been shown to be a function of the amount of that substance reported one day prior for the vast majority of participants. To our knowledge this methodology has not been applied to daily marijuana use.

Further, these studies have focused exclusively on samples that have reached regular, daily levels of substance use, limiting the generalizability of findings across levels of use. Due to the expectation that established users would be most influenced by short-term pharmacologic effects of a given substance, with few exceptions (Rosel & Elosegui, 1994), time series studies have focused solely on the predictive value of the closest substance use observations (i.e. the first autocorrelation or lag 1). Time series procedures also allow for an examination of the effect of more distal or seasonal influences of past substance use on the prediction of future use (Velicer & Fava, 2003). As substance use is driven and/or sustained not only by pharmacologic effects, but also by social and personal influences, seasonal patterns may also be prominent.

The present study employs a longitudinal design with weekly follow-back records of daily substance use across the entire first year of college. The following questions are addressed: 1) What individual patterns of tobacco smoking, alcohol and marijuana use exist among first year

college students and which are most prominent?; and 2) What predictive patterns are present within individual substance use behaviors? Univariate time series methods were employed to characterize detailed within-person substance use patterns and common patterns. In comparison to focusing on *average* population trends, the present study has the potential to capture the variability present among individuals and subgroups within this U.S. college population.

Method

Participants

The data collection and research protocol were approved by the Institutional Review Board at Purdue University. Participants were selected from responses to a screener survey (N=4690) administered to first year students during the orientation program in the summer of 2002 (response rate 71%). Recruitment for the screener survey began with an oversized postcard mailed in mid-May to all incoming freshmen. The postcard told potential participants that they would have the opportunity to complete a confidential 10-minute survey titled "College Freshmen Health Behavior Survey" when they were on campus for orientation activities. They were told that the survey would be used to identify people who would be invited to participate in a major study on healthy living that would begin in August when they arrived at university for the school year. They were also informed that they would be paid \$5.00 in cash for completing the survey.

On campus, posters announcing the project were placed at all locations frequented by orientation participants. In addition, the counselors conducting all of the School activities for Day on Campus made a brief announcement reminding students about the survey and the survey locations. A flyer describing the survey was placed in each orientation packet distributed to students. In addition, Flyers were placed on campus sidewalks near key buildings. Signboards were located outside and inside the two sites for survey administration. Confidentiality was assured through the use of non-identifying subject numbers assigned during recruitment. Students under age 18 were not recruited.

In all, 2001 (42%) individuals completing the screener reported at least some experience with smoking (i.e. one or more puffs lifetime) and were invited by mail to participate in the study. Nine hundred and twelve (46%) of these individuals completed the baseline survey and were asked to take part in 35 weekly web-based surveys throughout their first year. The overall response rate for 35 weeks was 87%, 90% when students were on campus, 76% when they were not (i.e. fall, winter and spring breaks). The sample was 48% female and 68% of the participants were permanent residents of Indiana. 90% of the sample was Caucasian, 5% were Asian and 3% were Black. Thirty-four percent of the sample reported having a parent who had smoked daily, while only 16% of the sample reported having a sibling that had smoked daily. At the start of the survey, 37.5% of the sample reported plans to join a sorority or fraternity on campus.

Eighty-two participants were excluded from the analysis due to missing data on more than 30% of the observations (Rankin & Marsh, 1985; Velicer & Colby, 2005a, Velicer & Colby, 2005b). A comparison of participants dropped due to missing data and those included in the present analyses, showed similar levels of lifetime exposure to cigarettes, alcohol and marijuana. Since times series analyses are employed to detect predictable patterns of behavior, we also selected a minimum number of points of observable behavior. Thus, the present analyses focused on participants who reported using one or more of the three substances of interest (i.e. tobacco, alcohol or marijuana) on at least 50 days during their freshman year. One hundred nineteen participants were included in the analysis for their tobacco smoking, 141 for their alcohol use and 37 for their marijuana use.

Procedure

Each week, participants were asked to provide 7-day time-line follow-back reports on their tobacco smoking, alcohol consumption and marijuana use (Sobell & Sobell, 1992). Using a web-based survey protocol, participants were asked to enter the “number of cigarettes you smoked”, “the number of drinks you had” and the “number of times you smoked marijuana” on each day of the preceding week. For the present analyses, winter and spring vacation periods were removed as we were specifically interested in examining short and long term substance use patterns that could be tied to the academic schedule. Time series analysis uses data with evenly spaced observations to detect behavior patterns that may be present at regular intervals. Because the vacations are not regularly distributed across the year, this method would not be able to detect the meaningfulness of these events. Additionally, vacations represent the periods with the highest rate of missing data, making their impact on the findings less certain. Thus, 210 reporting days were analyzed (105 from each academic semester) representing 30 full weeks of data with an average response rate for the sample slightly over 90% for each week. Cash incentives of \$10 were given for each weekly survey to maximize participation.

Data Analyses

Univariate time series parameters were estimated for each participant and each substance (i.e. tobacco, alcohol and marijuana) separately (Velicer & Fava, 2003). We examined: 1) the tendency of the behavior to increase or decrease over time through the inclusion of both linear and quadratic *trend* terms in the time series model; and 2) the predictive relationship (i.e. correlation) among individual substance use observations over time through the estimation of autocorrelations from lag 1 (i.e. yesterday) through lag 21 (i.e. three weeks ago).

All data were fit with ARIMA (21,0,0) in which 21 lags were estimated after removing non-stationarity via trends and modeling the amount of (residual) use on a given day as a function of the amount of (residual) use in past days. More specifically, the analysis of each time series consisted of two steps. In the first step, the model specified above was fit to the series of 210 daily observations ($t=1$ to 210). The structural model consisted of linear and quadratic trend terms for a continuous time variable (with values 1 to 210), and a seven-level categorical variable for each day of the week to account for an average weekly pattern of substance use. With trend and seasonality removed, the residuals were modeled as autocorrelated errors up to lag 21 (three weeks in the past). This 21 day lag structure was selected due to the fact that these were exploratory analyses, and 21 lags was the upper limit that could be examined with this methodology. Backward elimination with staying criterion $p<.05$ was used to identify the significant autocorrelation terms that explained dependence among the residuals. Maximum likelihood estimation was used to simultaneously fit the coefficients β of the structural model and the coefficients ϕ_j ($j=1$ to 21) for the autocorrelation terms. This method corrects the OLS structural regression coefficients for the autocorrelation among the residuals. The linear and quadratic time variable coefficients were then coded for statistical significance (-1 for negative and significant, 0 for not significant, 1 for positive and significant) to classify trends of substance use over the span of the full 210 day study period. These trends were also examined based on individuals' overall level of use for each substance.

For the second step, each series of 210 observations was examined for periods of abstinence, i.e. for 56 or more consecutive days (8 or more weeks) of non-use. Periods of abstinence were found for nearly half of the smokers (26.9%) and marijuana users (17.4%) and for less than a third of the drinkers (1.4%). Missing values embedded between days of reported non-use were counted as days of non-use. The periods of abstinence were deleted from the series of 210 observations to create a series representing non-abstinence behavior, and the time variable was re-numbered to indicate days of non-abstinence from 1 to L , where $L \leq 210$ was the new length of the series. A model of the form above was fit to this series, with the same structural model

terms as in step one for de-trending the series, and a 21-lag autoregressive model for the dependence among the residuals. The autoregression coefficients were then coded for statistical significance (-1 for negative and significant, 0 for not significant, 1 for positive and significant) in order to classify patterns of habitual substance use over the span of the non-abstinence observations. These patterns were also examined based on individuals' overall level of use for each substance. Missing data were handled by the SAS® AUTOREG procedure using maximum likelihood methods (Brocklebank & Dickey, 2003).

Results

Substance Use Characteristics

Tobacco smokers (i.e. at least 50 occasions) reported smoking 4.0 cigarettes on average per day (SD=3.5, range, 0.46-15.8) on 64% of the 210 days of the study (SD=26.1, range, 24%-100.0%). Drinkers (i.e. at least 50 occasions) reported 2.3 drinks on average per day (SD=0.92, range, 0.7 – 5.5), 33% of days (SD=7.0, range, 24.4% - 53.3%), and marijuana users (i.e. at least 50 occasions) reported 1.1 occasions of use on average per day (SD=0.7 range, 0.41 – 3.35), 50.8% of days (SD=19.5, range 26.3% – 93.2%).

Notable differences were seen by day of the week. Among drinkers, all drank on one or more Thursdays, Fridays and Saturdays, 76% on at least one Wednesday and 63% on one or more Mondays and Tuesdays. For both smokers and marijuana users, more than 92% of the sample smoked at least once on any given day of the week, with the highest rates seen on Fridays and Saturdays.

Time Series

To estimate the univariate time series parameters for tobacco smoking, alcohol and marijuana use, the SAS AUTOREG procedure was used. The 210 observations for each substance were examined separately for each participant. Parameters corresponding to trend and within substance correlations (i.e. autocorrelations) were estimated through the following steps: 1) Daily consumption quantities were modeled and examined for significant trends. Two indicator variables for each substance representing linear and quadratic trends were created based on the resulting estimates: negative and significant (-1), non significant (0) or positive and significant (1). 2) Our model also included autocorrelations from lag 1 (i.e. one day prior) through lag 21 (i.e. 3 weeks prior) and we again created corresponding indicator variables for each lag (i.e. prior days) to reflect the significance of the autocorrelation as well as its direction: negative and significant (-1), non significant (0) or positive and significant (1). The 21 day structure was selected because it was the largest number that could be evaluated with this methodology.

Trend

Figures 1 through 3 provide daily data for individual subjects representing the most common trends for each substance. For smoking behavior, three separate trends were found as the most common and were each represented by 23.5% (n=28) of smokers. First, a combination of negative linear and positive quadratic trends were demonstrated in which overall decreases in smoking were seen across the academic year with a notable increase in smoking at years end. Also, a negative linear trend was demonstrated showing highest use at the beginning of the year and finally, no change in levels of smoking as demonstrated by non-significant linear and quadratic trends was the third common pattern. An additional trend that accounted for 14.3% (n=17) of smokers was a positive linear and positive quadratic trend in which overall increases in marijuana use were seen across the academic year with a pronounced increase at years end.

For alcohol use, a positive linear trend was found as the most common, showing general increases in drinking behavior across the academic year (24.8%, n=35) Three additional trends

accounted for a substantial proportion of drinkers. First, was a positive linear and positive quadratic trend with increases in drinking behavior that were most pronounced at year's end (19.2%, $n=27$). Also, a negative linear trend was found in which drinking was highest at the beginning of the year followed by a general decrease in drinking (17.0%, $n=24$). Finally, no change in levels of drinking was demonstrated by non-significant linear and quadratic trends for 18.4% of drinkers ($n=26$).

For marijuana use, no change was the most common pattern as demonstrated by non-significant linear and quadratic trends among 43.2% of the marijuana users ($n=16$). A negative linear and negative quadratic trend was also demonstrated in which highest use was seen at the beginning of the academic year followed by general decreases that were most pronounced at years end (35.1%, $n=13$). Finally, a positive linear and positive quadratic trend was demonstrated by 21.6% ($n=8$) of the marijuana users showing general increases in use that were most pronounced at year's end. No additional trends accounted for more than 5% of individual substance users.

Autocorrelations for Tobacco Smoking

When examining autocorrelation structures within individuals' time series data for tobacco smoking, significant associations between past and present behavior were seen in 117 (98.3%) participants. Figure 4 presents the overall proportion of cigarette users at each of the 21 lags with significant correlations between their tobacco smoking on any given day and the corresponding behavior at one-day intervals up to three weeks prior (i.e. 1 day through 21 days). The autocorrelations are illustrated by direction of the association (i.e. positive or negative). When examining autocorrelations patterns for each individual participant, one may consider patterns of day-to-day use by examining the significance for lags 1 through 4 (i.e. behavior 1 to 4 days prior). For smoking the most predominant pattern of significant correlations for this day-to-day behavior was a positive first order autocorrelation only ($n=77$, 64.7%), demonstrating that higher levels of tobacco smoking for these individuals on any given day was predicted by higher levels of use one day ago, while lower levels of smoking on any given day was predicted by lower levels of use one day ago (Mean autocorrelation=.41, SD 0.18). No significant correlations for any of the first 4 lags (i.e. behavior 1 to 4 days prior) was seen among 18 (15.1%) of participants. A positive first order and second order autocorrelation only accounted for an additional 13 (10.9%) participants (Lag1 mean autocorrelation=.34, SD 0.13; Lag 2 mean autocorrelation=.22, SD 0.69). There were no subjects with first, second and third order autocorrelation patterns, suggesting that periods of greater or lesser than average smoking tended to be short.

Patterns of week-to-week use were established by examining significant correlations 7, 14 and 21 days prior. Half of the sample showed no significant correlation at any of these weekly lags ($n=56$, 47.1%). The most common significant pattern was a positive correlation at lag 7 ($n=25$, 21.0%), suggesting higher levels of tobacco smoking for these individuals on any given day was predicted by higher levels of use on the *same day* one week prior, while lower levels of smoking were predicted by lower levels of use on the same day one week prior (Mean autocorrelation=.27, SD 0.10). Additional significant lag structures including positive lag 14 only ($n=9$, 7.6%, Mean autocorrelation=.25, SD 0.08) and positive lag 7 and 21 ($n=8$, 6.7%, Lag 7 mean autocorrelation=.25, SD 0.10; Lag 21 mean autocorrelation=.28, SD 0.06) were also patterns demonstrated among individual smokers. Among those individuals demonstrating a significant correlation one day prior (i.e. lag 1), 47, (39.5%) also showed a significant autocorrelation at one or more of the weekly lags.

Correlations for Alcohol Use

Significant correlations for alcohol use were seen in 123 (87.9%) participants. Figure 5 presents the overall proportion of individuals at each of the 21 lags with significant correlations between their drinking on any given day and the corresponding behavior at one-day intervals up to three weeks prior (i.e. 1 day through 21 days). When examining day-to-day patterns (lags 1 through 4) for each individual participant, the most predominant pattern for drinking was a positive first order autocorrelation only ($n=58$, 41.1%) (Mean autocorrelation=.23, SD .07). No significant correlations for any of the first 4 lags were seen among 77 (54.6%) participants. None of the participants demonstrated significant first, second and third order autocorrelation patterns suggesting that periods of greater or lesser than average drinking tended to be short.

For patterns of week-to-week drinking (7, 14 and 21 days prior), the majority of the sample showed no significant correlations at any of these weekly lags ($n=93$, 66.0%). The most common significant lag structures included a *positive* auto-correlation at lag 7 only ($n=12$, 8.5%, Mean autocorrelation=.20, SD 0.04), a *negative* autocorrelation at lag 14 only ($n=9$, 6.4%, Mean autocorrelation=-.18, SD 0.03) and a *negative* autocorrelation at lag 21 only ($n=6$, 4.3%, Mean autocorrelation=-.21, SD 0.04). Each of the negative autocorrelation patterns suggest that *lower* levels of drinking for these individuals on any given day was predicted by *higher* levels of use on the same day during the prior weeks, while higher levels of drinking were predicted by lower levels of use on the same day in the weeks prior. Among those individuals demonstrating a significant correlation with behavior 1 day prior (i.e. Lag 1), 15, (10.6%) also showed a significant autocorrelation at one or more of the weekly lags.

Correlations for Marijuana Smoking

When examining correlation structures within individuals' time series data for marijuana use, significant associations between past and present behavior were seen in 36 (97.3%) participants. Figure 6 presents the overall proportion of individuals at each of the 21 lags with significant autocorrelations between their marijuana smoking on any given day and that behavior at one-day intervals up to three weeks in the past (i.e. 1 day through 21 days). When examining day-to-day use of marijuana (lags 1 through 4) the most predominant pattern of significant autocorrelations was again a positive first order autocorrelation only ($n=21$, 56.8%, Mean autocorrelation=.39, SD 0.16). No significant autocorrelations for any of the first 4 lags was seen among 4 (10.8%) of participants. A positive first order and either second order (Lag 1 mean autocorrelation=.43, SD 0.19; Lag 2 mean autocorrelation=0.21, SD 0.06) or third order autocorrelation (Lag 1 mean autocorrelation=.43, SD 0.09; Lag 3 mean autocorrelation=0.17, SD 0.02) accounted for an additional 29.7% of the sample.

Patterns of week-to-week use were again established by examining significant autocorrelations at lags 7, 14 and 21. More than two-thirds of the sample showed no significant autocorrelation at any of these weekly lags ($n=22$, 59.5%). The most common significant lag structures were negative auto-correlations at one of the weekly lags ($n=4$, 10.8%), suggesting lower levels of marijuana use for these individuals on any give day was predicted by higher levels of use on the *same day* in the weeks prior, while lower levels of marijuana use were predicted by lower levels of use on the same day in the weeks prior (Lag 7 mean autocorrelation=-.17, SD 0.05; Lag 14 mean autocorrelation=-.18, SD 0.05; Lag 21 mean autocorrelation=-.16, SD 0.06). Among those individuals demonstrating a significant autocorrelation at Lag 1, 27.0% ($n=10$) also showed a significant autocorrelation at one or more of the weekly lags.

Discussion

This study examined reports of daily substance use from a sample of first year U.S. college students in order to uncover variability in individual patterns of day-to-day use. Overall, results

indicated 1) higher rates of substance use at the beginning and/or end of the academic year for a substantial subset of the sample; and 2) significant predictive relationships between day-to-day substance use observations with some weekly patterning of behavior. Several previous studies of college students have shown that rates of smoking and tobacco dependence increase steadily over the college years (Bachman, Wadsworth, O'Malley, Johnston, & Schulenberg, 1997; Chassin, Presson, Rose, & Sherman, 1996; Sher, Gotham, Erickson, & Wood, 1996) with the majority of new cases identified after freshman year (Jackson, Sher, & Wood, 2000). This stands in contrast to patterns of alcohol and marijuana use where involvement is highest in the freshman year and then declines over subsequent college years (Jackson et al., 2000; Mohler-Kuo, Lee, & Wechsler, 2003). With few exceptions (Del Boca, Darkes, Greenbaum, & Goldman, 2004), previous work examining college trends in substance use have relied on cross-sectional or panel data collected once each year. In comparison, the sparse amount of research currently available on college samples collected at more fine-grained intervals, while useful in describing the fluctuations in substance use more fully, have typically focused on population averages that likely mask the variability present among unique subgroups of the population.

Our person-centered examination of daily substance use revealed more varied trends. Among those individuals with a significant trend in their tobacco smoking, alcohol and marijuana use, highest levels were often reported at the beginning and/or end of the academic year. In fact, higher rates of use at the beginning and end of the academic year have been similarly demonstrated in a recent study focusing on weekly alcohol consumption among college freshman (Del Boca, et al., 2004).

Rosel and Elosegui (1994) demonstrated a significant 7-day seasonal pattern of smoking among participants recruited from a university psychology course suggesting correlations in substance use behaviors based on day of the week, with consistently higher rates of use exhibited on weekends and substantially lower rates on weekdays. Further, their study showed a more complicated autoregressive structure for just over half of the sample, where smoking on any given day was shown to be a function of smoking on *multiple* previous days, often including significant autocorrelations one day prior as well as one and two week intervals prior. Our results confirm the predictive value of multiple previous days in that autocorrelation structures for participants were often complex.

Unlike Rosel and Elosegui's findings (1994), for drinking, the weekly patterns were often negative suggesting lower than average levels of use following higher levels. Negative autocorrelations have been previously demonstrated based on more proximal observations among heavy smokers (Velicer et al., 1992). The demonstration of negative correlations among weekly observations, particularly prevalent among lighter compared to heavier drinkers may suggest a process of substance use control (i.e. the decision to reduce levels of use following higher than average levels of use) that is lost as use patterns become more established. Not surprisingly, day of the week represents a particularly strong contextual variable among college students where academic demands reduce occasions for substantial substance use on weekdays, while weekends denote a significant reduction in those demands coupled with greater opportunity for use. Demonstrated patterns of consumption by day of the week in the present sample as well as other college samples (Del Boca et al., 2004) have clearly suggested high rates of abstinence on Sunday through Wednesday, with increasing use on Thursday and highest levels of use on Friday and Saturday.

Taken together, these patterns of relationships between substance-use observations suggest the importance of factors beyond the pharmacological effects on the underlying behavioral processes. Individual factors such as stress (Kassel, Stroud, & Paronis, 2003) and social factors such as substance use among peers (Oetting & Donnermeyer, 1998) have been proposed to

play a role in the development of substance-use behavior. In fact, the complex significant lag structure that we identified for tobacco smoking, drinking and marijuana use suggests the possibility of additive and/or synergistic effects of drug action with a wide range of other contextual and intra-individual influences (Brandon, Herzog, Irvin, Moffitt, & Gwaltney, 2004; Eissenberg, 2004; Glautier, 2004; Tiffany, 1990).

This study represents a number of firsts. While time series procedures have been utilized to examine patterns of substance use among chronic users (Velicer et al., 1992), to our knowledge this is the first study to include participants representing a wider range of substance use levels. Further, while daily measurement of natural episodes of tobacco smoking or drinking have been examined in separate studies (Del Boca et al., 2004; Rosel & Elosegui, 1994), this is the first to examine these patterns for marijuana use using such fine-grained reports of in vivo use. As this kind of intensive behavioral measurement is particularly challenging in terms of time, retention, and resources, previous studies utilizing time series to characterize longitudinal substance use patterns have typically relied on the description of only a handful of participants (Velicer et al., 1992). By comparison, the present sample represents the largest to date and provides greater generalizability for the individual patterns identified. A further strength of this study was the availability of 210 observations, a number which far exceeds the minimum recommended number for Times Series analyses ($N=100$) and improved our ability to estimate with less bias and more precision (Glass, Wilson & Gottman, 1975). Finally, the narrow age range, homogenous context and selection of a transition point in adolescent development permitted a relatively straightforward examination of time effects without confounding of multiple ages, stages and contexts.

It should be noted that while assessment was frequent, it was based exclusively on self reports of retrospectively recalled behavior during the previous week. While some questions have been raised regarding the accuracy of self-reported smoking, the advantages of using self-monitoring techniques are commonly believed to outweigh the disadvantages (Patrick et al., 1994; Stanton, McClelland, Elwood, Ferry, & Silva, 1996). For example, reports of number of cigarettes smoked per day have been shown to be a valuable index of smoking heaviness, being positively correlated with level of CO, cotinine and nicotine in group data (Heatherton, Kozlowski, Frecker, Rickert, & Roninson, 1989). A further limitation was the examination of individual substances without incorporation of influences of polysubstance use. Not surprisingly, several participants in the study met inclusion for multiple substance use behaviors. Notably, the bivariate form of time series methodology allows for the consideration of cross-correlations between the day to day patterns of *two* behaviors and has been previously examined in the present sample for alcohol and smoking (Dierker et al., 2006). To date, methodology entertaining the cross-correlations of more than two behaviors is unavailable.

Certainly, future research is needed to establish the generalizability of substance use patterns described in the present study. Although U.S. college students engage in higher levels of alcohol use than their non college peers, they have been found to exhibit less tobacco use (Johnson, O'Malley, & Bachman, 1996), the reasons for which may influence emerging patterns. Further, the racial homogeneity of the present sample limits our ability to generalize to more diverse populations. However, our high rates of adherence may have been linked to the college environment where computers are readily available, communication through electronic mail is the norm and a sense of community involvement in the project could be more readily established. It will be important to evaluate the feasibility of this sort of frequent monitoring of behavior in both more diverse samples and under less ideal conditions. Finally, while careful informed consent procedures were followed in this study, benefits to participants in terms of substance use cessation were not direct. This should continue to be weighed against the benefits of conducting this type of behavior monitoring study in the future (Kleinig, 2004).

The present results have implications for prevention aimed at college populations. First, some degree of targeted programming seems warranted. That is, the contingencies associated with the weekend/weekday schedule seem to influence a substantial subgroup and should be considered in designing intervention. Through day-to-day evaluation of in vivo substance use, the present study provided unique insights into the patterns and predictive relationships within tobacco smoking, alcohol and marijuana use during the critical transition to college and across the first academic year. Procedures such as time series analyses that allow for evaluation of within-person variability and change should continue to be employed in order to move beyond the more common consideration of population averages into better understanding of unique behavioral pathways that may be characterized on diverse dimensions. Research utilizing the detailed measurement demonstrated in the present study is needed to begin to articulate complex behavioral processes.

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Glossary of Terms

Time Series, Analysis that accounts for the fact that data points taken over time may have an internal structure (such as autocorrelation, trend or seasonal variation) that should be accounted for.; Autocorrelation, A correlation coefficient between two values of the same behavior at successive time intervals, rather than the correlation between two different behaviors.; Trend, Overall increases or decreases in behavior, both linear and curvilinear (i.e. the general direction).; Seasonal Variation, Significant autocorrelation between a behavior measured on any given day and that behavior measured at regular intervals in the past (e.g. weekly, monthly, etc).; Lag, A fixed time displacement (measured in the present study as days)..

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Figure 1.
Examples of most common smoking pattern (negative linear/positive quadratic, negative linear and no trend)

Figure 2.
Example of most common alcohol use pattern (positive linear).

Figure 3.
Example of most common marijuana use pattern (no trend)

Figure 4.
Proportion of Participants by Direction of Significant Tobacco Smoking Lag (N=119)

Figure 5.
Proportion of Participants by Direction of Significant Alcohol Use Lag (N=141)

Figure 6.
Proportion of Participants by Direction of Significant Marijuana Smoking Lag (N=37)