Incidence and patterns of polydrug use and craving for ecstasy in regular ecstasy users: An ecological momentary assessment study

James W. Hopper [a,*], Zhaohui Su [b], Alison R. Looby [a], Elizabeth T. Ryan [a],
David M. Penetar [a], Christopher M. Palmer [a], Scott E. Lukas [a]

[a] *Behavioral Psychopharmacology Research Laboratory, Department of Psychiatry, Harvard Medical School and McLean Hospital,
115 Mill Street, Belmont, MA 02478, United States*
[b] *Statistical and Data Analysis Center, Harvard School of Public Health, 651 Huntington Avenue, Boston, MA 02115, United States*

Abstract

Background: Previous studies employing retrospective assessments methods found that regular ecstasy users frequently use alcohol, marihuana and other drugs in combination with ecstasy.
Methods: Twenty-two participants (13 males, 9 females) wore a wrist actigraph/data recorder to record real-time drug use and ecstasy craving for 6 weeks. Rates of alcohol and drug use on ecstasy use versus non-use nights, and before, during, and after ecstasy use were analyzed with generalized estimation equations (GEE). Craving was modeled with GEE and linear mixed models.
Results: Approximately 70% of ecstasy uses occurred on Friday or Saturday nights. No drug was significantly more likely to be used on ecstasy use nights than comparison Friday and Saturday nights. On nights ecstasy was used, in general across all drugs assessed, use was more likely before and during than after ecstasy intoxication, while alcohol use was also more likely before than during ecstasy intoxication. Though low overall, craving for ecstasy increased over 24 h before use and was higher on Friday nights of weeks ecstasy was used on weekends than weeks it was not used.
Conclusions: Use of ecstasy on a particular night may not be associated with any greater likelihood of using any other intoxicating drug, and use of other drugs on nights involving ecstasy use may simply reflect a "natural history" of drug-use nights that begins with alcohol, progresses to more intoxicating drugs, and ends with little drug use. Confirmation of these findings awaits further advances in the application of ecological momentary assessment methodologies.
© 2006 Elsevier Ireland Ltd. All rights reserved.

Keywords: MDMA; Ecstasy; Drug abuse; Polysubstance abuse; Ecological momentary assessment

1. Introduction

Users of ecstasy (3,4-methylenedioxymethamphetamine or MDMA), particularly regular users, also use alcohol, marihuana and other illicit drugs at high rates and frequencies relative to comparison groups (Forsyth, 1996; Topp et al., 1999, 2004; Cottler et al., 2001; Parrott et al., 2001; Winstock et al., 2001; Bobes et al., 2002; Gross et al., 2002; Strote et al., 2002; Degenhardt and Hall, 2003; Scholey et al., 2004). Regular ecstasy users report using other drugs along with ecstasy and to deal with "coming down" during the period of acute recovery from its effects (Forsyth, 1996; Topp et al., 1999, 2004; Winstock et al., 2001; Verheyden et al., 2003).

The interactive effects of other drugs and ecstasy, particularly in the context of dancing at raves and nightclubs, may cause dehydration, hyperthermia, and several conditions that can lead to adverse effects including organ damage, neurotoxicity, and even death (Parrott et al., 2001; Cole and Sumnall, 2003). Further, regular ecstasy users can develop dependence and tolerance (Jansen, 1999; Cottler et al., 2001; Parrott, 2005) and take high and multiple doses over the course of a night, which in turn may lead to greater use of other drugs to "enhance" or "manage" desired and undesired ecstasy effects. Thus, it would be helpful to have valid and reliable data on patterns of other drug use along with ecstasy, particularly in regular ecstasy users.

In prior studies, ecstasy users in Australia and the United Kingdom have been asked whether they ever used alcohol or other drugs with ecstasy (Winstock et al., 2001; Topp et al., 1999), which drugs they first used and most commonly used with ecstasy (Topp et al., 1999; Verheyden et al., 2003), which

drugs they have used with ecstasy in the past year (Degenhardt and Hall, 2003), and how often they used these other drugs with ecstasy (Topp et al., 2004). The drugs most commonly used with ecstasy were tobacco, alcohol, marihuana, and amphetamine. Rates of co-using cocaine, LSD and nitrites with ecstasy varied from relatively high (58%) to low (10%) in the different studies. Three studies have investigated which drugs are used to assist with the "come down" from ecstasy (Forsyth, 1996; Winstock et al., 2001; Topp et al., 1999), and found that cannabis, alcohol, and benzodiazepines were most common. Only one study assessed drugs used before ecstasy (Forsyth, 1996), and found that amphetamines and cocaine were most commonly used by regular rave attendees in Edinburgh, Scotland.

To date, all studies of using other drugs along with ecstasy have employed interviews and questionnaires to elicit retrospective self-report data. These methods have several limitations, including the fallibility of reconstructive recall (Blair and Burton, 1987; Friedman, 1993; Sudman et al., 1996) and specific issues related to reporting prior substance use (Morral et al., 2000; Johnson and Fendrich, 2005).

In addition, while more knowledge is needed about use of other drugs along with ecstasy, another interesting question is whether or not rates at which other drugs are used on ecstasy use nights differ from rates of their use on nights when ecstasy is *not* used. That is, the conventional wisdom and media-promoted belief that ecstasy itself is disproportionately associated with – and perhaps even proximally causative of – using other illicit drugs has not been subjected to empirical investigation.

There are a number of different methods used to measure craving, ranging from a single 100 mm visual analog scale (Gawin et al., 1989) to lengthy multidimensional instruments (Tiffany, 1990). Despite the lack of agreement regarding the concept of craving, it is accepted that craving is a common feature associated with many drugs of abuse. Although the craving state may have a greater impact during relapse, the fact that drugs belonging to different classes can induce a similar subjective state suggests that there are more commonalties than differences with respect to drug-seeking behavior (cf. Pickens and Johanson, 1992; Meyer, 2000; Self, 1998).

Clinicians and researchers have stressed the importance of craving because of its potential utility as a marker of clinical status, including as a predictor of impending drug use. Thus, if a high level of craving reliably preceded drug use, one could target treatment interventions at (a) preventing craving, (b) reducing craving if it occurs, and (c) providing strategies to prevent drug use even in the presence of intense craving. However, in studies using retrospective self-report methodologies craving has been shown to be an inconsistent predictor of subsequent use in studies involving adults (Kosten, 1992; Pickens and Johanson, 1992; Weiss et al., 1995). Moreover, even if measured in real-time, craving may not be found to lead to drug use, for example because of resistance to use even in the presence of craving (Avants et al., 1995; Greeley et al., 1993; Herbst et al., 1996). Anton (2000) posited that the decision to use drugs or not results from an interaction between the level of craving and the resistance to drug use, and that the relative balance of these two factors determines drug use. In addition, for those attempting to

maintain abstinence, capacities for coping with craving and self-perceived efficacy (Bandura, 1977; Marlatt and Gordon, 1985) are important factors in determining whether craving leads to drug use or lapses (e.g., Baer et al., 1986; Gulliver et al., 1995; Shiffman et al., 2000).

In the current study, we employed "ecological momentary assessment" (EMA; Stone and Shiffman, 1994; Shiffman and Stone, 1998), also known as "experience sampling" (e.g., Simons et al., 2005) to overcome limitations of retrospective self-report methodologies and assess regular ecstasy users' craving for ecstasy and real-time drug use behaviors, including use of alcohol and other drugs along with and independently of ecstasy. EMA studies have employed a variety of methods for collecting real-time data in research participants' natural environments. At its most comprehensive, hand-held computers can be used to obtain detailed data on substance use, internal states, situational factors, and other aspects of experience in daily life, including prior to and during drug use, lapses and relapses. For example, in the study of relapse to drug use behavior, EMA has been used with smokers to document the association between smoking and situational cues, stressful and other events, affect, and craving (e.g., Shiffman et al., 1996, 2002; Shiffman and Waters, 2004).

For the purposes of documenting ecstasy and other drug use while individuals attend parties, clubs and/or raves, we used an EMA methodology at the simpler and less obtrusive end of the continuum. Our approach employs a wrist actigraphy device with an input button that allows participants to instantly record their drug use behavior in real-time, and to record drug craving in response to periodic audible prompts. It was our hope the simplicity and resulting non-obtrusiveness of this EMA approach, by allowing real-time sampling of frequent behaviors (specific uses of ecstasy, alcohol, and other drugs by polysubstance users) would offset its lack of assessment complexity. Another key limitation of this approach is the inability to detect failures of event recording. That is, if a participant drinks a can of beer and does not enter it into the device at the time, there is no way to know that this omission has occurred. Diary data can be collected to determine whether a certain event type happened at all during a particular day, but diary data are far less reliable than EMA data (Stone et al., 2002; Broderick et al., 2003), and any discrepancies found in this way could be underestimates. In contrast, response compliance to the audible prompts to record craving intensity can be determined, and pilot data indicated good compliance consistent with that found in other EMA studies (i.e., 85% and higher) during waking hours over 1- to 3-week periods.

We studied a convenience sample of regular ecstasy users who wore the actigraph device and recorded ecstasy, alcohol, marihuana, cocaine and other substance use every day for 6 weeks, and responded to prompts to record craving intensity. We had three aims: (1) to assess patterns of ecstasy use and its relationship to use of other drugs in the daily lives of young adult regular ecstasy users; (2) to determine whether patterns of using alcohol, marihuana, and other drugs besides ecstasy were different on nights when ecstasy was used from similar nights on which ecstasy was not used; (3) to assess patterns of craving for ecstasy over the hours preceding and following its use, and on days of weeks ecstasy was used versus not used. Due to concerns

about the validity of extant findings based on retrospective self-reports, we had no a priori hypotheses for this exploratory and descriptive study.

2. Methods

2.1. Participants

Thirty-four participants (24 males, 10 females) aged 19–38 were initially recruited via newspaper and internet advertisements (i.e., Craigslist©), and screened via a telephone interview. Participants who passed the phone screen were invited to the laboratory for a physical and mental status examination. They were accepted into the study if they (1) had been using ecstasy at least once per month over the prior 3 months, (2) were not taking psychotropic medications, (3) were physically healthy as determined by physical exam, including a normal electrocardiogram, and (4) did not currently meet criteria for DSM-IV axis I psychiatric disorders except for alcohol or substance abuse or dependence. For women, a negative pregnancy test was required.

Participants were told that the study was designed "to test the usefulness of a new wristwatch data recording device for use in natural setting studies." They were informed that the device can be used to record the frequency of drug use as well as changes in their desire to use drugs, and that they would wear it continuously for 6 weeks. The study's protocol was reviewed and approved by the McLean Hospital Institutional Review Board. Participants read and signed an informed consent before any study procedures were performed and were paid for their participation in the study. All were enrolled between April 2002 and September 2004.

2.2. Procedures

After providing informed consent, all participants completed study intake procedures consisting of a physical examination, urine drug screen, Structured Clinical Interview for DSM-IV Axis I Disorders (SCID-I), drug use history questionnaire, and the Beck Anxiety Inventory (BAI) and Beck Depression Inventory (BDI-II). Upon confirmation that inclusion but not exclusion criteria were met on enrollment, participants were trained in the use of the ActiWatch®-Score device (Mini-Mitter Co., Sun River, OR) and given daily diary forms to complete (detailed below).

Over the next 6 weeks until study completion, participants returned to the laboratory approximately every 7 days for collection of their wrist device and daily diary data, and completion of anxiety and depression questionnaires. They were provided with a new actigraphy device and data from the previous week were collected (detailed below). At each visit participants were administered breathalyzer and urine tests to assess for recent alcohol and substance use (and for women, pregnancy).

2.3. Ecological momentary assessment of drug use and craving for ecstasy

The ActiWatch®-Score is a battery-operated activity monitor device that is worn like a wristwatch. The user interface consists of a speaker that delivers audible prompts, a single manually operated input button, and an LED screen. Users can enter data at any time, or in response to audible prompts programmed by the experimenter (e.g., to record drug craving). The LED screen remains off until the user presses the input button. With each button press, the screen displays a successively higher number, from 0 to 9 (if the correct number is accidentally passed, users can cycle from 9 back to 0 by continuing to press the button). When the user has not pushed the input button for more than 3 s, the currently displayed number disappears and, along with the current time (to the second), is stored in the unit's on-board memory chip. The unit also contains an accelerometer motion detector that records the occurrence and degree of physical motion. Data collected on the wrist-worn device are transmitted via an interface reader to PC-based software, for display and export to statistical software for analysis.

In the current study, participants were instructed to wear the device at all times except when in the shower, bathtub, or swimming, and two kinds of participant-entered data were collected: drug use and craving for ecstasy. Partic-

ipants were given small laminated cards with numbers corresponding to drugs they might use in their daily lives. The drugs and codes were as follows: alcohol (1), tobacco (2), caffeine (3), cocaine (4), marihuana (5), study medication (not used in present study) (6), ecstasy (7), hallucinogens (8), opiates (9), and other (10). Participants were instructed to record, at the time of occurrence, whenever they took a pill, drank an alcoholic or caffeinated beverage, and every time they smoked a cigarette, by entering the correct number code that corresponded to the drug that they had just taken.

Ecstasy use was defined as taking a single tablet, but multiple tablets taken simultaneously were not recorded. An alcoholic beverage was defined as one beer, one glass of wine or one mixed drink. A caffeinated beverage was defined as one 12 or 16 once can or bottle of a caffeinated soft drink or one cup of coffee. (Participants were instructed not to take any over-the-counter products containing 100 mg or more of caffeine; a list was provided.) For marihuana, participants were instructed to record each smoking "session," alone or with others. For cocaine, recorded units were a snorted "line" of powder or smoked "bowl" of crack. For the remaining drug categories, participants were instructed to record each use. Instructions for recording drug use, including definitions of recordable use events for each drug type, were provided both verbally and in writing.

Subjectively experienced craving for ecstasy was collected by periodically prompting participants with audible alerts from the ActiWatch. Participants were told that whenever they heard the prompt they should enter their "craving or desire to use ecstasy at that exact moment on a scale of 0–9, with 0 being not at all and 9 being extreme." The unit was programmed to prompt participants approximately every 3 h (a randomly determined number of minutes within 20 min before or after a 3 h interval). The brief audible prompt repeats every second for 10 s or until the participant enters a numeric value with the input button, whichever is shorter. The prompt is typically not loud enough to awaken participants during sleep, as was confirmed by all participants in the current study. Sleep/wake activity was collected but is not presented in this report.

Participants also were instructed to complete, upon awakening each day, diaries about selected experiences and behaviors the preceding day. Likert items addressed mood, ability to concentrate, appetite, sleep, anxiety, irritability, physical tension and agitation, and physical symptoms, and asked, "How strong was your desire to use ecstasy in the past 24 h?" Participants were also asked to record their drug use for each of the drugs they were required to enter into the x device, including the names of drugs entered as "other". Finally, participants were asked when they went to bed (regardless of when they went to sleep) and got up from bed.

At each weekly study visit, the daily diaries were collected and data from the ActiWatch was downloaded and returned to the participant for the next week of recording. A research assistant then verified that the participant had been wearing the device (as indicated by actigraphy data) and recording substance use and craving as instructed. ActiWatch and daily diary data were inspected for missing entries and inconsistencies between them. Participants were also questioned about any mistaken ActiWatch entries that required correction (this was very rare).

2.4. Data reduction

A primary aim for this study was to describe patterns of other drug use along with ecstasy, as assessed with a device capable of recording drug use when it actually occurred. To accomplish this goal, we first demarcated three equal blocks of time within ecstasy use nights to capture use of other drugs (1) before using ecstasy, (2) during the time ecstasy had been taken and the plateau of its effects, and (3) after the ecstasy "high" had passed and the participant would presumably choose to use other drugs (at least in part) to self-medicate unwanted physiological and/or psychological correlates of "coming down" from ecstasy.

For "before" ecstasy use, we used the 4 h preceding the participant's (first) use of ecstasy that night. For "during" we used the time period from (first) use to 4 h later, because the onset of ecstasy effects typically occurs 40–90 min after self-administration and the drug effect plateau from a single dose may last up to 3 h. For "after" ecstasy use, we were interested in use of other drugs while "coming down," and demarcated this period as 4–8 h after the last use of ecstasy on a given night. While this approach did not allow assessment of all drug use

from 4 h after (last) ecstasy use until going to sleep, for comparability purposes it was necessary to use equal time intervals for each of the three periods. (On seven nights when ecstasy was used, by six participants, they went to sleep more than 8 h after their last use or did not go to sleep the entire next day; for these, the 8 h cut-off was necessarily arbitrary.) As described below, these time periods were used to assess relative probabilities of using different drugs before, during, and after ecstasy.

To compare the use of drugs on nights when ecstasy was used to nights when ecstasy was not used, probabilities of using a drug at any time during the entire night, defined as 5:00 p.m.–9:00 a.m., were calculated on a per participant basis. As 30% of ActiWatch-recorded ecstasy uses occurred on nights other than Friday and Saturday, only Friday and Saturday were used as comparison nights; this conservative approach limited comparison non-use nights to those most likely to involve substance use. Friday and Saturday nights for which participants reported using ecstasy on daily diaries but not on the ActiWatch (see below) were excluded from analysis. (For several reasons, including different sleep times and variability in times of first (and last) ecstasy use within participants, it was not possible to validly compare drug usage during analogous before, during and after periods of nights when ecstasy was not used.)

To reduce craving data, which were collected at 3 h intervals, we divided each day into eight 3 h blocks (actually 3 h ± 20 min, due to the pseudorandom prompting program described above).

2.5. Data analyses

Descriptive statistics were calculated for demographic data, drug use histories, psychiatric disorders and symptoms, and response rates to prompts to record ecstasy craving. Data completeness and concordance between data collected with the ActiWatch and daily diaries were also examined. Data were analyzed primarily using SAS8.2 (Cary, NC).

Appropriate inferential statistics were employed to analyze use of drugs, in temporal relation to ecstasy use and in comparison to use on Friday and Saturday nights when ecstasy was not used. As necessary preliminary analyses were conducted to determine the structures and distributions of the data, then the most appropriate method was applied.

One crucial characteristic of the drug use data, anticipated from the outset, was that ecstasy use nights were distributed across study participants who exhibited individual differences in patterns of using ecstasy and other drugs. For example, some participants used ecstasy only one time during the study, while others used ecstasy several times. These characteristics of the data required nesting drug use data within participants.

Binary (yes/no) drug use outcomes were modeled with generalized estimating equations (GEE; Lipsitz et al., 1991, 1994a, 1994b; Miller et al., 1993), fitting in the Genmod procedure. Logit link function and binomial error distribution of multivariate responses (i.e., before, during, and after periods) were specified. (For these and all GEE analyses described below, multiple covariance structures, including unstructured, autoregressive and exchangeable, yielded identical findings.) The odds ratios for pair-wise comparison of use of each drug before, during, and after ecstasy were computed. Comparisons were also made of the odds ratios for use of each drug on nights when ecstasy was used versus Friday and Saturday nights when ecstasy was not used.

Though we collected data on use of several types of drugs, we were most interested, a priori, in use of alcohol and marihuana. Therefore, two families of analyses were conducted when investigating patterns of drug use: first, analyses on alcohol and marihuana; second, analyses for other drugs and use of *any* intoxicating drug (i.e., alcohol and any illicit drug besides tobacco and caffeine). Within each family of analyses, the Bonferroni method was used to adjust the significance level for multiple comparisons.

For alcohol, caffeine, and tobacco, continuous measures of usage were also available. A GEE model with identity link function and normal error distribution for drug use entries from participants was used to compare the consumption of alcohol, caffeine, and tobacco during the different time intervals on ecstasy use nights. The Bonferroni method was used to adjust for multiple comparisons.

For analysis of the craving data, we first assessed response rates to the craving prompts for each participant to determine whether any participants should be removed from subsequent analyses due to low response rates. Next a GEE model with identity link function and normal error distribution was used to compare response rates between nights when ecstasy was used and was not used.

To fit craving data from 24 h before and 24 h after ecstasy use, linear mixed effect model with repeated measurements was used. Here, participant was modeled as a random effect, and measurements from the eight 3 h blocks in each ecstasy use night were modeled as repeated measurements for each participant. The AR(1) covariance structure within each ecstasy use night nested within each participant was specified. This covariance structure was chosen based on the nature of the problem and comparisons of the AIC and BIC values of different covariance structures. (We chose to use the SAS Mixed procedure rather than GEE because GEE, as implemented in the SAS software Genmod procedure, cannot model the repeated measurement within each ecstasy use night nested within each participant.)

For comparisons of craving levels on days of weeks when ecstasy was used versus weeks when ecstasy was not used, it was particularly unclear a priori what the structure of the data would be or which analytic approach would be most appropriate. (For example, consistent with the 24 h analyses, craving was expected to vary systematically within ecstasy use days, defined as 9:00 a.m. one calendar day to 8:59 a.m. the next.) Since for every participant, the craving for ecstasy was expected to be different for each day of the week, we only compared the craving levels on the same day of the week for weeks when ecstasy was used versus weeks when it was not (e.g., Sunday versus Sunday, Monday versus Monday). Inspection of the data revealed that it was appropriate to use a GEE model, with identity link function and normal error distribution for craving scores from the two different types of week for the same subject. The dependent variable is the mean craving level for each day of the week for each subject. Data from weeks on which ecstasy was used on nights other than Friday or Saturday were excluded from these analyses, in order to assess whether different patterns of craving were associated with weeks on which ecstasy was used on the weekend versus weeks it was not, since the great majority ecstasy uses occurred on Friday and Saturday nights (which are also the highest drug-use nights of the week). As a secondary analysis, based on observed prominent peaks and troughs in the daily craving data, peak craving level for each day of the week was also modeled using the same procedure described above.

3. Results

3.1. Demographic data and drug use histories

Of the total 34 participants recruited, 6 did not start or complete the ActiWatch protocol, and 6 completed the protocol but did not use ecstasy. Of the 22 participants who completed the protocol and used ecstasy at least once during the study, 13 were males and 9 females with a mean age of 22.8 ($\pm$13.5) years, 16 (73%) were Caucasian and 2 (9%) each were African American, Hispanic and Asian. All but 1 of the 22 had a high school education, 20 had taken some college courses, 8 had college and 2 had graduate degrees. Twenty were single, one living with a partner and one divorced. In terms of employment and education status, 8 were unemployed, 9 full-time and 5 part-time employed, 14 were not in school, 7 were students full time and one part time. The 12 enrolled participants who did not use ecstasy and/or complete the protocol had comparatively more males and minorities; they were also much heavier alcohol drinkers than those who remained in the study and used ecstasy (22.8 ($\pm$13.5) drinks versus 8.7 ($\pm$6.3) drinks per week, $t(13.67) = 3.43$, $p = 0.004$). The following results are for the 22 participants who completed the protocol and used ecstasy at least once during the study.

Additional drug history data, with the exception of cigarette smoking, are presented in Table 1. These data indicate that participants were regular ecstasy, alcohol, and marihuana users,

Table 1
Frequencies and prevalences of self-reported drug use history, for participants using ecstasy during the study (*n* = 22)

	Participants per prior-use category		Prevalence (%) of use	
	0|1–4|5–10|11–39|40+			
	Lifetime	Past 30 days	Past year	Past 30 days
Ecstasy	0|0|4|4|14	1|21|0|0|0	100	100
Alcohol	0|0|0|3|19	0|6|7|7|2	100	100
Marihuana	0|0|0|0|22	3|4|5|6|4	100	86.4
Cocaine	3|2|3|7|7	11|8|3|0|0	81.8	50.0
Stimulants	8|2|1|5|6	15|6|1|0|0	54.5	31.8
Hallucinogens	1|4|3|5|9	9|9|4|0|0	72.7	59.1
Sedatives	12|5|0|5|0	19|3|0|0|0	27.3	13.6
Opiates	11|3|3|3|2	21|1|0|0|0	36.3	4.5

and that most had used cocaine, stimulants, hallucinogens, and sedatives. Fifteen (68%) had been regular smokers of cigarettes at some time in their lives, and 12 (55%) currently smoked regularly at a mean rate of approximately two packs per week.

3.2. Psychiatric disorders and symptoms

Aside from substance use disorders, the only DSM-IV Axis I psychiatric disorders were two participants (9.1%) with past major depressive disorder and one (4.5%) with current substance-induced mood disorder. Continuous measures of anxiety and depressive symptoms were very low, with a mean BAI score of 2.68 (±2.66) and a mean BDI-II score of 6.36 (±5.07).

In terms of prevalence of current and past substance use disorders, nearly one-fourth were currently dependent on ecstasy, and approximately one in six met current or past criteria for ecstasy abuse. About one-third were dependent on marihuana, and nearly one-quarter met criteria for current or past marihuana abuse. While none were dependent on alcohol, almost one-fourth met criteria for current alcohol abuse. Rates of abuse and dependence for other drugs, both past and current, were low and never more than one or two of the participants.

3.3. Data completeness and concordance between ActiWatch and daily diary reports of drug use

Due to compliance and scheduling issues, the final study day on which a participant entered both ActiWatch and daily diary data typically did not match. Thus we first determined the final study days on which each participant provided both ActiWatch and diary data, and based completeness and concordance analyses on all study days up to that day.

Of the 22 participants who used ecstasy, 10 entered ActiWatch and daily diary data for the entire 6 weeks or 42 days of the protocol, and another 7 provided data from both sources for more than 42 days (with maximum of 47 from one participant). Four participants provided both sources of data for 31–41 days, and one for 17 days.

Completeness analyses for the ActiWatch data revealed that, across all participants, for 89.5% or 682 of 762 days the device was worn for the entire day and did not malfunction. The same analysis was conducted for ecstasy use days and comparison Fridays and Saturdays (9:00 a.m.–9:00 a.m. next day, to include periods involving early morning drug use), indicating that on 90.8% or 238 of 262 days participants wore a functioning device for the entire day. The majority of days (58%) with missing ActiWatch data were due to participants not wearing the device the entire day.

Concordance analyses could only be conducted on study days for which participants had provided both forms of data, and the following results are based on study days for which both forms of data were available, with data for other missing days (in the middle of the study) addressed as missing data.

Participants reported 64 ecstasy use days on the ActiWatch, and 76 in their daily diaries. Of 64 ecstasy use days reported by participants on the ActiWatch 4 or 6.3% were not reported on the diaries, and 4 participants accounted for these discrepancies. Of 76 ecstasy use days reported in the daily diaries 16 or 21.1% were not reported on the ActiWatch; 14 of these were due to participants not wearing the device that day or night, and 2 were due to device malfunction.

We assessed the concordance between entire waking days of ActiWatch reports (waking hours, not 12:00 a.m.–11:59 p.m.) and corresponding daily diary reports. Table 2 reports results of concordance analyses on ActiWatch versus daily diary reports of drug use. Separate results are reported for (1) all drugs for ecstasy use days and comparison Fridays and Saturdays on which ActiWatch and daily diary data are available (days used in subsequent analyses), and (2) drugs other than ecstasy for the 54 days for which (a) ecstasy use was recorded in the ActiWatch, (b) there was complete ActiWatch data for waking hours, and (c) ecstasy use was also recorded in the daily diary. As revealed by inspection of Table 2 and standard interpretive guidelines (Landis and Koch, 1977), on days with data available from both sources, agreement was quite high overall (90%, kappa = 0.78); very high for ecstasy, tobacco, cocaine, and marihuana; substantial for alcohol, opiates and other drugs; and only moderate for caffeine. Similar and higher levels of concordance were found for days on which ActiWatch and diary entries matched for ecstasy use (with the exception of opiates; only one use was reported via the ActiWatch, and none on the diary).

Table 2
Concordance between recordings of drug use with ActiWatch and daily diary (excludes days without complete ActiWatch data during waking hours)

Drug	Days with both daily diary data and an entire day of ActiWatch data available				Days with Actiwatch and diary available and agreement on ecstasy use			
	Concordance			Kappa	Concordance			Kappa
	Agree	ActiWatch not diary	Diary not ActiWatch		Agree	ActiWatch not diary	Diary not ActiWatch	
Ecstasy (%)	206 (92.0)	4 (1.8)	14 (6.3)	0.80				
Alcohol (%)	185 (82.6)	23 (10.3)	16 (7.1)	0.62	48 (88.9)	2 (3.7)	4 (7.4)	0.71
Marihuana (%)	199 (88.8)	7 (3.1)	18 (8.0)	0.77	47 (87.0)	1 (1.9)	6 (11.1)	0.74
Cocaine (%)	210 (93.8)	8 (3.6)	6 (2.7)	0.80	52 (96.3)	0 (0)	2 (3.7)	0.92
Opiates (%)	221 (98.7)	1 (0.4)	2 (0.9)	0.72	53 (98.1)	1 (1.9)	0 (0.0)	0.66
Tobacco (%)	205 (91.5)	8 (3.6)	11 (4.9)	0.83	49 (90.7)	2 (3.7)	3 (5.6)	0.81
Caffeine (%)	176 (78.6)	10 (4.5)	38 (17.0)	0.57	48 (83.3)	4 (5.6)	6 (11.1)	0.66
Other (%)	209 (93.3)	6 (2.7)	9 (4.0)	0.64	52 (96.3)	0 (0)	2 (3.7)	0.84
Total (%)	1611 (89.9)	67 (3.7)	114 (6.4)	0.78	346 (91.5)	9 (2.4)	23 (6.1)	0.83

3.4. Patterns of ecstasy use during the study

Ecstasy use patterns during the study can be described based on ActiWatch and daily diary data. Because this study was designed to address drug use assessed in real-time, and because of serious concerns about the accuracy of daily diary data, including whether it was actually recorded each morning as opposed to estimated all at once just before turning in diaries at a study visit (Hufford et al., 2002), we focused on the Acti-Watch data.

According to the ActiWatch data, there was a mean of 2.91 ecstasy use days per participant during the course of the study. Fig. 1 graphically presents percentages for days and times of day that ecstasy use was reported on the ActiWatch, and the number of times ecstasy was used each night it was used, across the 64 use nights. These results were essentially identical for the diary data.

For nights with multiple ecstasy uses, time intervals between reported successive ecstasy uses were derived from ActiWatch data. The number of minutes between first and second uses ranged from 30 to 172 min with a mean of 94 min (±43.4); third uses took place from 35 to 115 min after second uses with a mean of 69 min (±27.2); fourth uses occurred 42, 43, 46 and 52 min after third uses. Tablets per usage were not recorded with the ActiWatch (and were not reliably reported on the daily diaries).

Finally, we estimated the duration of ecstasy use episodes. Consistent with our definition of the "during" period, because the onset of ecstasy effects typically occurs 40–90 min after self-administration and the drug effect plateau lasts up to 3 h, we calculated the duration of ecstasy use episodes from the time the first dose was taken to 4 h after the last dose. Based on these calculations, across all participants the mean duration of ecstasy use episodes was 5 h, and the median was 4 h; for episodes involving more than one ecstasy use, the mean duration was 7 h and 8 min and the median was 6 h and 30 min. The participant who reported nine uses of ecstasy in one night took the last dose 7 h and 35 min after the first, which would correspond to 11 or more hours of ecstasy intoxication.
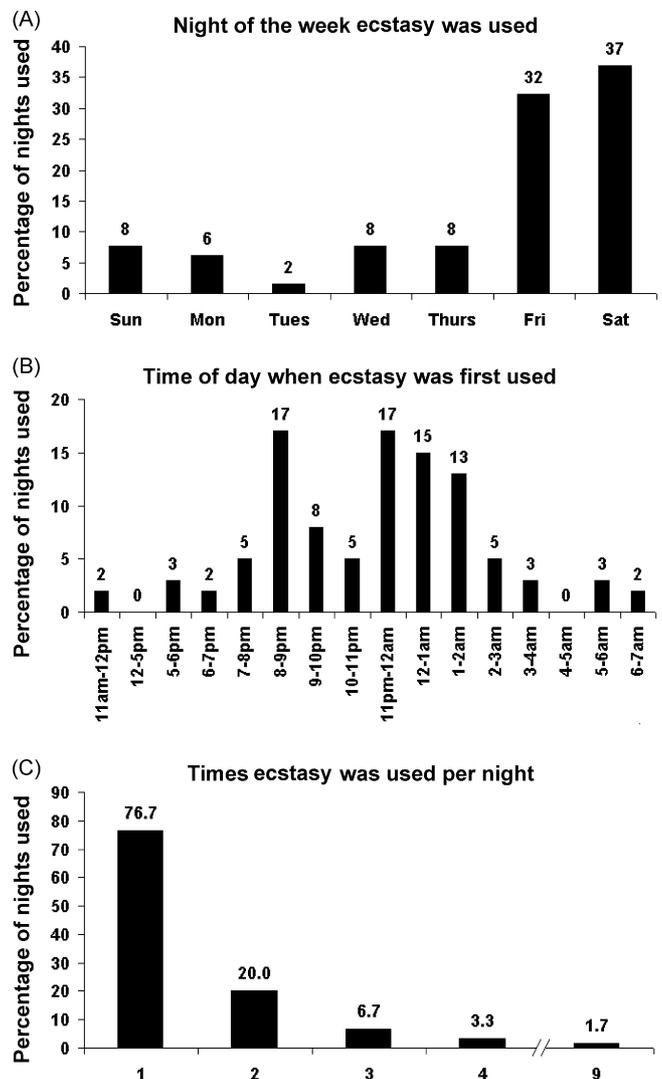
Fig. 1. (A) Nights of the week that ecstasy was used, (B) time of day when ecstasy was first used during each night, and (C) number of times used per night. Data are from 60 use nights reported on the ActiWatch by 22 participants.

Table 3
Results of generalized estimating equation models used to compare drug use on nights when ecstasy was used vs. comparison Friday and Saturday nights when ecstasy was not used, expressed as odds ratios (ecstasy use nights/ecstasy non-use nights)

Drug[a]	Ecstasy use nights (%)	Non-use nights (%)	Odds ratio	Standard error	p-Value	95% Confidence interval	
						Lower	Upper
Alcohol	60.5	54.1	1.303	1.490	0.597	0.597	2.844
Marihuana	43.2	49.7	0.773	1.362	0.403	0.422	1.416
Cocaine	22.6	12.3	2.074	1.413	0.035[†]	1.053	4.084
Tobacco	45.0	44.9	1.003	1.287	0.991	0.611	1.645
Caffeine	28.9	20.3	1.596	1.328	0.100	0.915	2.785
Any intoxicating drug	82.7	77.5	1.383	1.615	0.499	0.541	3.536

[a] Odds ratio could not be calculated for hallucinogens, opiates or the "other drug" categories, due to low incidences of use during the study.

[†] Marginally significant after Bonferroni correction for categories other than alcohol and marihuana ($p = 0.0125$).

3.5. Patterns of using other drugs in the presence or absence of ecstasy use

As indicated in Table 3, the GEE models revealed that of all the drugs assessed, no drug was significantly more likely to be used on nights (liberally defined as 5:00 p.m.–9:00 a.m.) that ecstasy was used than on comparison Friday and Saturday nights not involving ecstasy use. After correction for multiple tests, there was a trend for cocaine use to be more likely on ecstasy use nights than ecstasy non-use nights.

For these analyses, odds ratios could not be calculated for hallucinogens or opiates, or for the "other drug" category, because there were insufficient observations due to low incidences of participants' using these substances during the study. The "any intoxicating drug" category did include these substances, but no difference in use likelihood as a function of night type was found.

Because participants were instructed to use the ActiWatch to record each and every alcoholic beverage, caffeinated beverage and tobacco cigarette consumed, it was possible compare the number of reported uses of each substance during the periods before, during, and after ecstasy use. These data were highly non-normally distributed. Consistent with the binary results, GEE models testing for differential amount of use for these drugs revealed no statistically significant differences (after correction for multiple tests with a significance threshold of 0.0167). For tobacco, the only drug with even a marginally significant result ($p = 0.042$), the estimated greater amount used on ecstasy use nights was relatively inconsequential, at 1.3 cigarettes (95% CI = 0.05–2.53).

3.6. Patterns of using other drugs on nights when ecstasy was used

As described above, to account for variability across participants and situations, GEE was used to compare binary outcomes for consumption of alcohol, caffeine, and tobacco during the different time intervals on ecstasy use nights. Table 4 presents results of these models across the drugs assessed.

The primary analyses concerned alcohol and marihuana. Use of alcohol was significantly more likely before than during or after ecstasy intoxication, and there was a trend for a greater likelihood of using alcohol during ecstasy intoxication than afterward. The odds ratio for likelihood of using alcohol before versus after ecstasy was extremely high (81.0 with a lower 95% confidence interval of 11.2). For marihuana, there were greater likelihoods of using marihuana before and during ecstasy intoxication than afterward, with the period during ecstasy intoxication being particularly likely to involve marihuana use compared to the 4 h coming down period (OR = 16.4). There were also marginally significant trends, after correction for multiple tests, for greater likelihood of using alcohol than marihuana before ecstasy intoxication, and greater likelihood of using marihuana than alcohol while high on ecstasy.

The second family of GEE models, on rates of using other drugs and any intoxicating drug before, during and after ecstasy, revealed significant and marginally significant differences in likelihood of using "other drugs" (see Section 3.5) before, during and after ecstasy for several drug categories. In terms of significant effects, use of tobacco and any intoxicating drug were more common before and during ecstasy intoxication than afterward, and use of cocaine was more likely during than after ecstasy intoxication. There were insufficient data for the GEE models to compare likelihood of using hallucinogens or opiates during the three time periods. See Table 4 for detailed results.

GEE models also were used to compare consumption levels of alcohol, caffeine, and tobacco during the different time periods on ecstasy use nights. After correction for multiple tests (Bonferroni corrected significance levels of 0.0056), only one significant effect was found. That is, consistent with the results of the binary (use/non-use) analyses, significantly more alcoholic beverages were reported consumed before taking ecstasy than after ecstasy intoxication ($p = 0.001$). However, consistent with the findings of between-nights analyses, the estimated consumption differential amounted to less than half of an alcoholic beverage (0.48, upper 95% CI = 0.76). Marginally statistically significant and even less practically significant effects were found for greater consumption of alcoholic or caffeinated beverages before than during ecstasy intoxication, and more cigarettes smoked during than afterward.

Finally, we used our data to address the "rule of thirds," the conventional wisdom that one-third of ecstasy users tend to use alcohol with ecstasy, another third with marihuana, and another third with neither alcohol nor marihuana. Use patterns in our sample of regular ecstasy users did not support this view. For example, out of 10 participants who used ecstasy at least three

Table 4
Results of generalized estimating equation models used to compare likelihoods of drug use before, during, and after ecstasy

Drug[a]	Periods	Percent using	Odds ratio	Standard error	p-Value	95% Confidence interval	
						Lower	Upper
	Before/during	90.0/45.0	11.000	1.954	0.0003[*]	2.959	40.900
Alcohol	Before/after	90.0/10.0	81.000	2.744	<0.0001[*]	11.206	585.507
	During/after	45.0/10.0	7.364	2.202	0.0114[†]	1.568	34.585
	Before/during	66.7/74.1	0.700	2.291	0.6670	0.138	3.555
Marihuana	Before/after	66.7/14.8	11.500	2.032	0.0006[*]	2.865	46.155
	During/after	74.1/14.8	16.429	1.540	<0.0001[*]	7.046	38.307
Alcohol/Marihuana	Before	89.5/67.2	4.150	1.914	0.0284[†]	1.163	14.813
Marihuana/Alcohol	During	73.3/47.5	3.029	1.585	0.0161[†]	1.229	7.468
	After	14.9/11.8	1.313	2.051	0.7045	0.321	5.368
	Before/during	47.6/61.9	0.559	3.010	0.5981	0.065	4.849
Cocaine	Before/after	47.6/14.3	5.455	2.421	0.0551[†]	0.964	30.867
	During/after	61.9/14.3	9.750	1.857	0.0002[*]	2.898	32.806
	Before/during	80.6/74.2	1.449	1.769	0.5155	0.474	4.434
Tobacco	Before/after	80.6/32.3	8.750	1.917	0.0009[*]	2.445	31.320
	During/after	74.2/32.3	6.038	1.316	<0.0001[*]	3.527	10.334
	Before/during	65.2/39.1	2.917	1.742	0.0537[†]	0.983	8.652
Caffeine	Before/after	65.2/26.1	5.313	2.350	0.0506[†]	0.996	28.342
	During/after	39.1/26.1	1.821	2.348	0.4823	0.342	9.703
	Before/during	44.4/88.9	0.100	4.907	0.1477	0.004	2.259
Other drug	Before/after	44.4/22.2	2.800	2.797	0.3167	0.373	21.014
	During/after	88.9/22.2	28.000	5.114	0.0412[†]	1.143	685.927
	Before/during	88.1/67.8	3.529	2.098	0.0887	0.826	15.071
Any intoxicating drug	Before/after	88.1/22.0	26.286	2.059	<0.0001[*]	6.382	108.266
	During/after	67.8/22.0	7.449	1.521	<0.0001[*]	3.275	16.944

For each drug category, if the drug was not used at some time during those three time periods, the night was excluded from analyses.

[a] "Other drug" is other drug than those listed and opiates, for which low incidence prevented calculation of odds ratios.

[*] Significant after Bonferroni correction (for marihuana and alcohol analyses, $p = 0.0056$; for all other analyses, including any intoxicating drug, $p = 0.0042$).

[†] Marginally significant, $p < 0.06$.

times during the study, only one consistently used only alcohol with ecstasy (four of four uses), and six used alcohol *and* marihuana on some ecstasy use nights but alcohol *or* marihuana on at least one other night.

3.7. Craving for ecstasy

First, responses rates to ActiWatch prompts (during waking hours, when the device was being worn and functioning properly, as confirmed by actigraphy data) were assessed for overall compliance per participant. In addition, response rates were compared for nights when ecstasy was used and comparison Friday and Saturday nights when ecstasy was not used (with response rates from the same participants treated as pairs), to assess for a possible non-response bias that could influence subsequent analyses. One participant had an extremely low response rate (3%), and was excluded from all analyses of craving for ecstasy. As described below, specific criteria were applied for selecting participants for inclusion in the 24 h and day-of-week craving analyses.

Consistent with the detailed information provided in Table 5, across the 21 remaining participants (overall response rates over 20%), there was a significantly lower response rate on ecstasy use than comparison non-use nights (GEE, $p = 0.035$).

A subsequent analysis, to determine whether this difference was attributable to using ecstasy versus using any intoxicating drug, revealed that the effect of using ecstasy remained even only in comparison to nights when other intoxicating drugs were used.

Debriefing interviews suggested that, for the vast majority of missing data points, participants did not hear the relatively quiet prompt. Nonetheless, there were 3789 recorded craving ratings available from the 21 participants with response rates over 20% for the descriptive statistics presented in Fig. 2. Remarkably, a
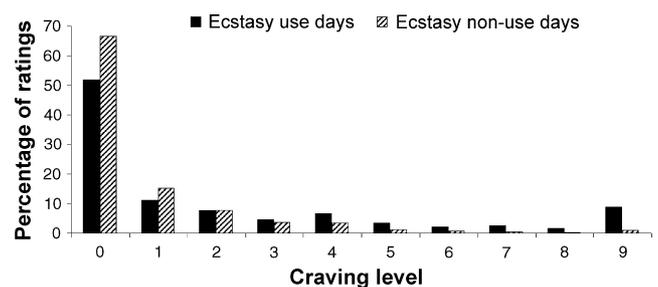

Fig. 2. Distribution of self-reported levels of craving ($n = 3789$) elicited from the 21 participants with greater than 20% response rates to ActiWatch prompts to record craving levels (administered approximately every 3 h; distribution was similar for the 18 participants with response rates greater than 40% and the 10 with response rates over 66%).

Table 5
Response rates during waking hours to prompts to record level of craving for ecstasy

Participant	Response rate (%) (responses/prompts)			
	Non-use nights	Use nights	Mean across type of night	Difference between type of night
19	42.5 (117/245)	0.0 (0/18)	21.3	42.5
3	57.5 (149/259)	0.0 (0/6)	28.8	57.5
8	68.4 (171/250)	20.0 (3/15)	44.2	48.4
7	54.0 (101/187)	51.6 (32/62)	52.8	2.4
2	56.1 (97/173)	50.0 (1/2)	53.0	6.1
12	67.1 (112/167)	50.0 (6/12)	58.5	17.1
1	62.2 (145/233)	57.1 (4/7)	59.7	5.1
15	67.8 (156/230)	53.1 (17/32)	60.5	14.7
14	65.6 (172/262)	60.0 (12/20)	62.8	5.6
6	70.3 (156/222)	58.3 (7/12)	64.3	11.9
17	79.4 (154/194)	52.0 (26/50)	65.7	27.4
11	71.8 (145/202)	61.1 (11/18)	66.4	10.7
4	61.0 (128/210)	72.2 (13/18)	66.6	−11.3
20	76.5 (205/268)	57.1 (8/14)	66.8	19.3
18	67.8 (120/177)	66.7 (16/24)	67.2	1.1
13	75.7 (143/189)	66.7 (4/6)	71.2	9.0
16	76.1 (181/238)	68.2 (15/22)	72.1	7.9
5	60.1 (116/193)	84.6 (11/13)	72.4	−24.5
9	75.6 (127/168)	79.5 (31/39)	77.5	−3.9
21	77.3 (174/225)	100.0 (4/4)	88.7	−22.7
10	78.9 (142/180)	100.0 (6/6)	89.4	−21.1
Mean	67.2	57.5	62.4	9.7

The participant with an extremely low response rate (3%) is excluded, and the remaining 21 are ordered by mean response rate across ecstasy use and non-use nights. Response rates are calculated from data corresponding to when the ActiWatch was functional and being worn by the participant (see text for details).

value of zero (for "not at all") was entered for 52% of craving ratings during waking hours on days involving ecstasy use and 70% of craving ratings on days not involving ecstasy use (aggregated across participants). While craving levels reported during ecstasy use days were consistently higher than those reported during non-use days, most markedly so for the highest rating (i.e., 9 on the scale of 0–9), only 8.8% of ratings across ecstasy use days were at this highest possible level.

To address the concern that data from the 21 participants are biased by a large proportion of missing data, these descriptive statistics were run for two other subgroups of participants: 18 participants with 40% or higher response rates on both ecstasy use and non-use nights (3264 craving ratings), as well as the 10 participants with the highest overall rates of responding (1931 craving ratings). For both groups, the distribution of craving levels was nearly identical to that found for the 21 participants with response rates over 20%.

The top of Fig. 3 presents results of the linear mixed modeling of craving over 24 h before and after ecstasy use. For these analyses, the 21 participants described above were included. After excluding ecstasy use nights for which ecstasy use occurred within 24 h of another ecstasy use, 52 ecstasy use nights (of 64 reported on the ActiWatch) were available for analysis. While craving was very low overall, even on days when ecstasy was used, there were clear linear and quadratic trends in craving levels over the 24 h preceding (first) ecstasy use (linear, 1.352 ± 0.209, $p = 0.0001$; quadratic, 0.124 ± 0.025, $p = 0.0001$.) For the 24 h after (last) ecstasy use, neither linear nor quadratic trends were present, but craving levels during the

6 h after taking the (last) ecstasy dose were significantly higher than craving levels from 9 to 24 h afterward. Indeed, as revealed by inspection of the figure and post hoc statistical comparison, a precipitous drop in craving for ecstasy is apparent from 6 to 9 h after last use (importantly, as noted above this analysis excluded ecstasy use nights followed by ecstasy use within the next 24 h). We repeated the analyses on craving 24 h before using ecstasy with the 18 participants having response rates above 40% overall and on ecstasy use nights, as well as the 10 participants with the highest response rates on both ecstasy use and non-use nights. The results were unchanged, with highly significant linear and quadratic terms. Results for analyses of craving over the 24 h after ecstasy use were also unchanged for those subsamples.

As indicated in the bottom of Fig. 3, consistent with the 24 h craving results, there tended to be daily troughs in craving around noon time and peaks around 9:00 p.m. or midnight (each "day" spans 9:00 a.m.–8:59 a.m. the next morning). Weeks when ecstasy was used on other than Friday and Saturday night were excluded from these analyses; weeks when ecstasy was used on both Friday and Saturday night were included. Based on the structure of the data, a linear mixed model was used to compare mean craving levels on the same days of the week for ecstasy use and non-use weeks (e.g., Sunday versus Sunday, Monday versus Monday). The model included participant as random factor, a term for week type (ecstasy use versus non-use), and mean craving levels for each day of the week as the dependent variables. For these analyses, only the 18 participants with response rates of 40% or higher on ecstasy use and non-use nights were included, because those with lower response rates
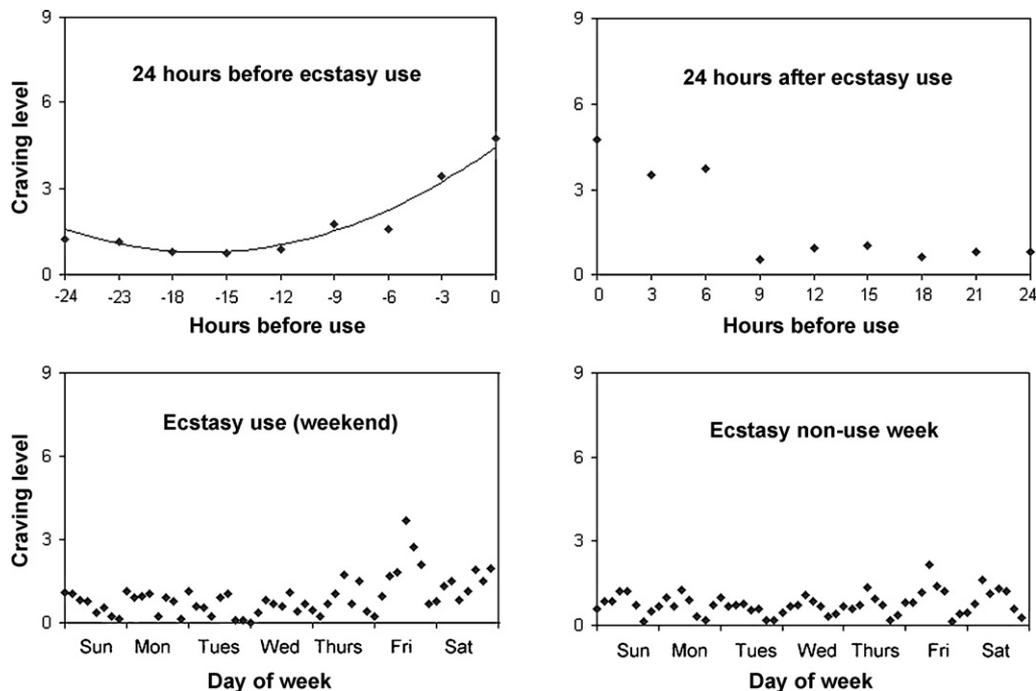
Fig. 3. Patterns of craving for ecstasy. Top panel: results of linear mixed models of craving levels 24 h before and after ecstasy use on a particular night (representing all 21 participants with >20% response rates to prompt, excluding 12 of 64 ecstasy use nights where ecstasy use on the following night occurred within 24 h of last ecstasy use on the previous night). Bottom panel: mean craving levels for 3 h intervals over days of the week during weeks when ecstasy was used on the weekend and weeks when ecstasy was not used at all ("day" corresponds to 9:00 a.m.–8:59 a.m. the next morning; representing 18 participants, excluding three with response rates <40% on ecstasy use and non-use nights).

provided insufficient numbers of observations for the GEE models. For these 18 participants, there were 31 weeks when ecstasy was used on Friday only (15 uses), Saturday only (10 uses), or both Friday and Saturday (6 uses, 3 weeks). After correction for multiple tests, only for Friday night was the mean craving level significantly greater for weeks involving ecstasy use on weekend nights versus weeks with no ecstasy use (GEE, hazard ratio = exp (0.3853) = 1.47, p = 0.0024). For Saturday night there was a moderate trend for higher craving on ecstasy use weeks (GEE, hazard ratio = 1.50, p = 0.0114). Results were similar for peak craving, with a significant difference for Friday night but no trend for Saturday or any other night. We repeated these analyses using only the 10 participants with the highest response rates on both ecstasy use and non-use nights. Again, the results were unchanged, with only Friday night having higher mean and peak craving levels on ecstasy use weeks than ecstasy non-use weeks.

4. Discussion

The present study provides the first empirical data on real-time ecstasy use in a population of regular users. Most notably, our findings suggest that in this study's sample of regular ecstasy users, contrary to the conventional wisdom, ecstasy use was not associated with increased likelihood of using other drugs. This appears to be the case for nights involving ecstasy, compared to Friday and Saturday nights not involving ecstasy use. This also appears true for nights involving ecstasy use, where use of ecstasy and others drugs appears to follow a "natural history"

that typically begins with alcohol, progresses to a period involving use of a highly intoxicating drug, in this case ecstasy, which is followed by significantly decreased likelihood of using any intoxicating substance.

4.1. Ecological momentary assessment methodology issues

As noted in Section 1, it was our hope that the simplicity and relative non-obtrusiveness of the ActiWatch would offset its lack of assessment complexity by allowing real-time sampling of frequent drug use behaviors. For the purpose of collecting drug use data, the ActiWatch method used in this study is simple because participants are only required to enter one piece of data at a time (i.e., what drug they just used), and relatively non-obtrusive by virtue of its small size, wrist watch-like form factor, and absence of audible prompts to enter drug use events. We did not anticipate, however, the low response rate to craving prompts and wide range of concordance between ActiWatch and daily diary drug use data.

In terms of drug use, concordance between ActiWatch and daily diary were relatively poor for alcohol and caffeine, and moderate for ecstasy, marihuana, cocaine and tobacco. This could indicate underreporting of use of these drugs via the ActiWatch, which could result in some drug-use occasions being analyzed as non-drug controls. However, well-established concerns about the validity of daily diary data (Hufford et al., 2002) suggests that jumping to conclusions about inaccuracy of ActiWatch drug use data based on these concordance findings is

unwarranted. Only additional research, including use of both participant- and device-initiated event logging, can shed light on how significant this limitation is, particularly whether it is associated with systematic data loss and biases associated with other key variables. In addition, future research employing both EMA and daily diary data could shed light on whether differential reporting rates for each method vary by drug type, which would have implications for self-monitoring EMA research on substance use patterns.

In terms of ActiWatch-recorded drug use data, there is a more serious methodological limitation. Because participants were required to record all drug use events as they occurred, rather than some drug use events when prompted to do so by the device, it is not possible to know whether lack of entry resulted from non-use or unrecorded use. This is an inherent limitation of such real-time self-monitoring EMA methodologies. On top of missing drug use events, incorrect classification of nights or time periods as non-use controls would bias the results of analyses. Importantly, for analyses of within-night drug use patterns, we have no data that shed light on whether compliance varies as a function of time relative to ecstasy use (or time of night). For analyses of drug use patterns on ecstasy use versus non-use nights, however, we could assess response rate by type of night (paired within participants), and did find a marginally statistically significant tendency for lower rates of responding to the craving prompt on ecstasy use nights than for ecstasy non-use nights. This suggests that such a bias, though not a large one, did affect comparisons of drug use on ecstasy use versus non-use nights.

For craving data, to record their craving level participants had to hear and respond to audible ("beep") prompts that repeated once a second for 10 s. The prompt volume was calibrated during pilot testing, and set at the highest level that would enable participants to wear the ActiWatch without them or their (sleeping) partners being awakened by the sound. Pilot data suggested that responses rates of 85% or higher could be expected at that volume level, though it was recognized that rates would be lower when participants were in loud environments including dance clubs and some parties. While debriefing indicated that most non-responses were due to not hearing the prompt, it is possible that participants may not have acknowledged ignoring or choosing not to respond to the prompt. Non-responding may also have resulted, at least in some situations and environments, from difficulty entering a craving rating during the 10 s time window allowed by the device.

In the future, compliance and response rates might be improved by modifications to the technology and/or data entry procedures that allow for delayed recording of craving ratings. If the technology can virtually assure that participants will be aware of each prompt, response rates might be increased by compensating participants in part based on the percentage of prompts they respond to while awake (as detected by actigraphy).

In summary, the main EMA-related methodological limitations of the current study are relatively low concordance between ActiWatch and diary reports of drug use, inability to distinguish non-entry of drug use events from actual non-use, and the relatively low response rates to the craving rating prompts. This

suggests that our results should be interpreted with caution until replicated in EMA studies that significantly overcome these limitations.

4.2. Patterns of ecstasy use

The ActiWatch data from this study are, to our knowledge, the first real-time data on ecstasy use patterns. In this sample of regular ecstasy users, the drug was most frequently used as a single dose on a Friday or Saturday night. This finding confirms anecdotal reports and retrospective survey study findings that most ecstasy use occurs on weekend nights. More than half of ecstasy use episodes commenced between 8:00 and 10:00 p.m. or 11:00 p.m. and 2:00 a.m., and 93% between 5:00 p.m. and 4:00 a.m.

For about 75% of the ecstasy use nights reported with the ActiWatch, ecstasy was only used once that night. Second ecstasy uses on the same night, reported 20% of the time, typically occurred between 45 min and 2.25 h after the first use. Second and (rare) additional doses were always taken within 3 h of the previous dose, suggesting that participants used ecstasy again because they were not satisfied with the effects of the prior dose(s) and/or they wanted to prolong the plateau of ecstasy intoxication. In future studies more valid (time-stamped) electronic diary data and qualitative interviews could clarify reasons for subsequent same-night doses and their timing.

4.3. Use of other drugs on ecstasy use nights versus nights when ecstasy was not used

A most noteworthy and important finding of this study is the absence of any significantly greater likelihood of using alcohol, marihuana, or any intoxicating drug on nights when ecstasy was used than on comparison non-use nights. There was only a statistical trend for greater likelihood of using cocaine on ecstasy use nights than ecstasy non-use nights. Nor were there any differences in the amount consumed for drugs with continuous data available, that is, alcohol, tobacco and caffeine. This suggests that, at least among regular ecstasy users, with the possible exception of cocaine, using ecstasy on a particular night is not associated with increased rates of using other drugs.

Indeed, based on our data, we suspect that regular ecstasy users are simply more likely to use a variety of drugs – including ecstasy and other than ecstasy – on weekend and other nights involving high levels of polysubstance use. If this is so, then findings from studies that ask participants which drugs they used on nights they used ecstasy, without *also* inquiring about use of those same drugs on (weekend) nights when ecstasy was not used, may result in spurious conclusions about the meaning of using other drugs with ecstasy. Furthermore, our results do not support the notion, often promoted in the popular media, that ecstasy use in particular is associated with using other drugs on the same occasion. However, the previously mentioned statistical trend for lower response rates to craving prompts, which might correspond to lower rates of entering drug use events, and the trend for greater likelihood of using cocaine on ecstasy use nights than non-use nights, suggests these

results should be interpreted cautiously and that more research is needed.

4.4. Patterns of other drug use on ecstasy use nights

Across all drug categories we studied, participants were more likely to use the drug before and during ecstasy intoxication than during the "coming down" period, defined here as four to 8 h after (last) ecstasy use. Given the uniformity of this finding across drug types, it appears to reflect the "natural history" of substance use over the course of nights involving ecstasy use, and perhaps nights involving drug use more generally. That is, participants were least likely to use any drug, however intoxicating, in the later part of the night. This might be attributable to fatigue or a "winding down" period at the end of nights involving substance use, particularly after intoxicating effects of ecstasy, likely the most powerful drug consumed, have passed.

Only for alcohol and caffeine were there significantly and marginally greater likelihoods, respectively, of using the drug before ecstasy intoxication than during ecstasy intoxication, defined here as 4 h before and 4 h after the (first) ecstasy dose was taken.

There are several possible and not mutually exclusive explanations for the much greater likelihood of using alcohol prior to ecstasy than while intoxicated on the drug (OR = 81). First, this too might reflect the natural history of drug use episodes or "nights of partying," with participants tending to drink alcohol before moving on to other drugs, including ecstasy. Second, impulsivity, poor judgment or diminished concern about the potential harm associated with alcohol-induced intoxication may render ecstasy users, particularly regular ecstasy users, more likely to seek out the drug or to accept it when offered. Finally, this may be a planned drug combination with intended pharmacological and psychological outcomes, with alcohol used proactively to diminish unwanted ecstasy effects or to facilitate desired effects that are also associated with alcohol intoxication, such as extraversion and disinhibition. Hernandez-Lopez et al. (2002) have demonstrated that alcohol–ecstasy combinations can result in a longer lasting euphoric response, and that ecstasy can reverse alcohol's sedative effects without altering degree of "drunkenness."

Pharmacological explanations for the greater likelihood of using caffeine before than during and after ecstasy are even more plausible. That is, participants likely consumed caffeine at the beginning of ecstasy use nights for stimulant effects desired during a long period of intoxication, socializing, postponed sleep, and perhaps dancing. Again, this is compatible with a natural history perspective.

Study participants were more likely to use alcohol than marihuana before taking ecstasy. In contrast, there was a trend for greater likelihood of using marihuana than alcohol during ecstasy intoxication. Perhaps, in these regular ecstasy users, greater use of marihuana than alcohol during ecstasy intoxication might be due to concerns about dehydration.

In the three retrospective self-report studies to address the issue of drug use while "coming down" from ecstasy intoxication, marihuana, tobacco and alcohol were reported as the substances most commonly used to assist with unwanted experiences during this phase (Forsyth, 1996; Winstock et al., 2001; Topp et al., 1999). Thus it is particularly noteworthy that, in the current study, these three drugs, like all other drug categories studied (with sufficient use to allow calculations of odds ratios), were more likely to be used before and during ecstasy intoxication than while coming down. It is conceivable but unlikely that such use occurs over a longer post-intoxication period than 4 h, the duration imposed by statistical considerations. Nonetheless, this study's findings suggest either that its participants have very different patterns of using other drugs while coming down than those in prior studies, or that memories for such use tend to be inconsistent with actual behavior.

Importantly, in this sample of regular ecstasy users we found no evidence that *any* drug was more likely to be used during ecstasy intoxication than before. This too would fit with a natural history of drug use over the course of nights involving ecstasy use, such that drug use decreases in likelihood as the night progresses and/or that taking a strongly intoxicating drug like ecstasy is associated with no increased likelihood of taking other drugs at the same time. Either way, this result again suggests that neither ecstasy use, nor ecstasy intoxication, independently increases the likelihood of using other drugs.

Rather, we believe that, overall, our findings are most compatible with the view that ecstasy is no different from any other highly intoxicating drug used within the natural history of drug use during nights involving multiple intoxicating substances. First, it tends to be used after some alcohol has been consumed. Second, during peak intoxication other drugs may be used but typically not highly intoxicating ones. Finally, use of other drugs is least likely at the end of the night, while coming down from its intoxicating effects. Importantly, drug use data from the current study did not allow empirical verification of this natural history interpretation; on too few comparison Friday and Saturday nights not involving ecstasy use were participants awake late enough to allow comparison of drug use during time periods analogous to the before, during and after intervals for ecstasy use nights.

The approach used in this study is quite different from previous questionnaire and interview approaches that have relied on retrospective estimates. In prior studies, ecstasy users likely relied on both schematic and episodic memory, accessed using multiple cognitive sets that are not necessarily apparent to the investigators – or perhaps even the participants themselves – to produce estimates across *all* of their prior ecstasy uses, or "typical" ecstasy uses, or ecstasy uses over a specific recent period of time. Thus, comparing our ActiWatch-based findings with those of prior studies or interpreting differences is not straightforward. For example, in prior publications it is not always apparent whether clear definitions (in temporal terms) of "with" or "while 'on'" were provided for participants, and whether or not these included the period we have defined as "before" ecstasy use. Nonetheless, it is noteworthy that the drugs reported in prior studies as most commonly used with ecstasy were alcohol, marihuana, tobacco and amphetamine (Topp et al., 1999; Winstock et al., 2001; Degenhardt and Hall, 2003; Verheyden et al., 2003). Aside from amphetamine, our findings concerning use of other

drugs within ecstasy use nights are consistent with those of prior studies.

Clearly the present findings on the timing and sequencing of ecstasy and other drug use during individual nights raise more questions than they answer. Future research will need to select and refine EMA methodologies to overcome the limitations of this study and others presented by EMA research. Studies utilizing observation and assessment in environments where ecstasy and other drugs are taken may provide the necessary data to clarify this issue. Finally, qualitative interviews could complement EMA data in informative and valuable ways.

4.5. Patterns of craving for ecstasy

As discussed previously, response rates to ActiWatch craving rating prompts were not high for an EMA methodology, and suggest that alternative prompting methods are required. Though the results of craving analyses were unchanged for participants with response rates greater than 40% and greater than 66%, caution is required with regard to these findings.

Interestingly, levels of craving for ecstasy were by and large quite low, even on ecstasy use nights, though the distribution of craving ratings was clearly skewed toward higher ratings on ecstasy use than non-use nights. Despite overall low craving levels, in the 24 h preceding (first) ecstasy use clearly rising levels of craving were found, with both linear and quadratic terms significant in the mixed model. Such a pattern of rather long cyclic and low intensity craving for ecstasy might differ from patterns for other drugs such as opiates, nicotine, cocaine, and amphetamine. That is, laboratory research on cue-induced craving suggests that craving for these conventional drugs of abuse can persist at relatively low and constant levels but escalate quickly to very high levels in response to drug-related cues (e.g., Childress et al., 1986; Ehrman et al., 1992).

Over the 24 h following (last) ecstasy use, there was a clear pattern of craving remaining relatively high until 6 h after ecstasy use, then dropping precipitously to nearly zero. This is not consistent with laboratory (e.g., DiFranza and Wellman, 2005; Bell et al., 1999) and outpatient clinical (e.g., Franken et al., 2002) studies suggesting that drug deprivation and withdrawal states are associated with high levels craving that rapidly declines after a single instance of drug use. Rather, the pattern of craving after ecstasy use is more like that observed for cocaine, which can remain high or even increase immediately after use. In the case of cocaine, this is presumably due to the rapid crash and the resultant desire to avoid it (Jaffe et al., 1989). For ecstasy, it may be that the intense positive feelings and experiences, though they last for hours, do not appreciably decrease craving for continued desired drug effects until well after they have passed. Finally, it is possible that prior research findings do not accurately represent patterns of craving in naturalistic settings, and the patterns we found for ecstasy using EMA with a temporal resolution of 3 h could resemble craving for conventional drugs assessed in the same way. Thus appropriately designed EMA studies of craving, which overcome limitations of prior laboratory and outpatient survey studies, are needed to determine whether, and if so to what extent, patterns of craving for ecstasy differ from those for conventional drugs of abuse.

Analyses of craving patterns suggest that craving peaks at higher levels on Friday nights when ecstasy is used than on Fridays when ecstasy is not used. Results were similar for comparisons of mean and peak daily craving. These results are consistent with these regular ecstasy users, on weeks they plan to use or anticipate using ecstasy, experiencing increased craving with the approach of the weekend, specifically the first weekend night likely to involve ecstasy use. However, our data do not reveal whether participants were planning to use ecstasy or only decided to on Friday or Saturday. In addition, it may be that the significant difference in craving between ecstasy use and non-use weeks for Friday but not Saturday nights is an artifact of the greater number of Friday-only than Saturday-only uses. The greater number of Friday-only weekend uses could also reflect greater craving on Friday than Saturday, or perhaps increased craving and increased likelihood of using ecstasy with the onset of the weekend. This issue could be clarified by qualitative follow-up interviews.

Based on the above findings and inspection of Fig. 3, one might speculate that craving for ecstasy partly exhibits a cyclical or wave-like function, with daily ebbs and flows superimposed on similar but longer cycles associated with weeks that do and do not involve weekend use. For example, polysubstance abusers who hold jobs and/or attend school may typically exhibit such mid-day troughs and evening peaks of craving for intoxicating drugs they use regularly, as well as greater peaks of nighttime craving on (weekend) nights that are (a) most likely to involve the (most) use of these substances and (b) least likely to involve adverse consequences on the following (non-work or non-school) days. Again, future research on patterns of craving for ecstasy and for more conventional drugs of abuse, particularly well-designed EMA studies including sophisticated sampling and statistical modeling approaches, as well as qualitative follow-up interviews, will be necessary to determine the validity of the current results for ecstasy and to assess similarities and differences with craving for other abused substances.

4.6. Addition methodological limitations

In addition to the methodological limitations already discussed, there are others that temper the interpretation of these findings. The convenience sampling strategy of this study, and its resultant sample consisting primarily of respondents to internet advertisements, are limitations that render it unlikely to be representative of regular ecstasy users in the United States, Australia, and Europe. Also very important, data were not collected on the number of ecstasy pills participants took each time they ingested ecstasy. Coupled with the fact that MDMA is not always present in pills that are sold as ecstasy, this particularly limits the interpretation of the pharmacological effects of ecstasy use on other drug use. In fact, drug use along with ecstasy may have been higher when the ecstasy dose was inactive, or when it contained another drug like dextromethorphan. This is not too problematic, however, because we were most interested in what participants perceived they were taking and how they reacted

to their perceptions and expectations. Finally, another related and important concern with this type of EMA study is whether the participants were too intoxicated, particularly later in nights involving alcohol and drug use, to remember and comply with the study instructions and enter all data reliably and validly.

4.7. Summary

In this first naturalistic study of polydrug use patterns in regular ecstasy users, we used an EMA approach that was relatively simple and unobtrusive but characterized by several methodological limitations. We found that 70% of ecstasy uses occurred on a Friday or Saturday night and 75% during the hours between 8:00 p.m. and 2:00 a.m. Contrary to the conventional wisdom, ecstasy use was not associated with increased likelihood of using other drugs. No drug was more likely to be used on nights involving ecstasy use than Friday and Saturday nights not involving ecstasy use. For nights involving ecstasy use, use of all drugs appeared to follow a "natural history" that began with use of alcohol, was followed by a period involving use of a highly intoxicating drug, ecstasy, and in turn followed by a period with significantly decreased likelihood of using any drug. Data on craving for ecstasy were least complete, and suggested patterns of relatively low craving in relation to occasions of ecstasy use, along with increasing craving in the run-up to use and greatest craving on Friday nights of weeks involving weekend use. Together these drug use and craving data offer new insights into the challenges of employing relatively minimalist EMA methods to study naturalistic polysubstance use and drug craving, and no support for the conventional wisdom about associations between use of ecstasy and other drugs of abuse.

Acknowledgements

References

Anton, R.F., 2000. Clinical relevance and measurement of craving in alcohol dependence. Presented at the 149th Annual Meeting of the American Psychiatric Association. New York, May 4–9.

Avants, S.K., Margolin, A., Kosten, T.R., Cooney, N.L., 1995. Differences between responders and nonresponders to cocaine cues in the laboratory. Addict. Behav. 20, 215–224.

Baer, J.S., Holt, C.S., Lichtenstein, E., 1986. Self-efficacy and smoking reexamined: construct validity and clinical utility. J. Consult. Clin. Psychol. 54, 846–852.

Bandura, A., 1977. Self-efficacy: toward a unifying theory of behavior change. Psychol. Rev. 84, 191–215.

Bell, S.L., Taylor, R.C., Singleton, G.E., Henningfield, J.E., Heishman, S.J., 1999. Smoking after nicotine deprivation enhances cognitive performance and decreases tobacco craving in drug abusers. Nicotine Tob. Res. 1, 45–52.

Blair, E., Burton, S., 1987. Cognitive processes used by survey respondents to answer behavioral frequency questions. J. Consumer Res. 14, 280–288.

Bobes, J., Saiz, P.A., Gonzalez, M.P., Bascaran, M.T., Bousono, M., Ricaurte, G.A., McCann, U.D., 2002. Use of MDMA and other illicit drugs by young adult males in northern Spain. A five-year study. Eur. Addict. Res. 8, 147–154.

Broderick, J.E., Schwartz, J.E., Shiffman, S., Hufford, M.R., Stone, A.A., 2003. Signaling does not adequately improve diary compliance. Ann. Behav. Med. 26, 139–148.

Childress, A.R., McLellan, A.T., Ehrman, R., O'Brien, C.P., Childress, A.R., McLellan, A.T., O'Brien, C.P., 1986. Conditioned responses in a methadone population. A comparison of laboratory, clinic, and natural settings. J. Subst. Abuse Treat. 3, 173–179.

Cole, J.C., Sumnall, H.R., 1998. Altered states: the clinical effects of ecstasy. Pharmacol. Ther., 35–38.

Cottler, L.B., Womack, S.B., Compton, W.M., Ben-Abdallah, A., 2001. Ecstasy abuse and dependence among adolescents and young adults: applicability and reliability of DSM-IV criteria. Hum. Psychopharmacol. 16, 599–606.

Degenhardt, L., Hall, W., 2003. Patterns of co-morbidity between alcohol use and other substance use in the Australian population. Drug Alcohol Rev. 22, 7–13.

DiFranza, J.R., Wellman, R.J., 2005. A sensitization-homeostasis model of nicotine craving, withdrawal, and tolerance: integrating the clinical and basic science literature. Nicotine Tob. Res. 7, 9–26.

Ehrman, R.N., Robbins, S.J., Childress, A.R., O'Brien, C.P., 1992. Conditioned responses to cocaine-related stimuli in cocaine abuse patients. Psychopharmacology (Berlin) 107, 523–529.

Forsyth, A.J., 1996. Places and patterns of drug use in the Scottish dance scene. Addiction 91, 511–521.

Franken, I.H., Hendriksa, V.M., van den Brink, W., 2002. Initial validation of two opiate craving questionnaires: The Obsessive Compulsive Drug Use Scale and the Desires for Drug Questionnaire. Addict. Behav. 27, 675–685.

Friedman, W.J., 1993. Memory for the time of past events. Psychol. Bull. 113, 44–66.

Gawin, F., Kleber, H., Byck, R., Rounsaville, B., Kosten, T., Jatlow, P., Morgan, C., 1989. Desipramine facilitation of initial cocaine abstinence. Arch. Gen. Psychiatry 46, 117–121.

Greeley, J., Swift, W., Heather, N., 1993. To drink or not to drink? Assessing conflicting desires in dependent drinkers in treatment. Drug Alcohol Depend. 32, 169–179.

Gross, S.R., Barrett, S.P., Shestowsky, J.S., Pihl, R.O., 2002. Ecstasy and drug consumption patterns: a Canadian rave population study. Can. J. Psychiatry 47, 546–551.

Gulliver, S.B., Hughes, J.R., Solomon, L.J., Dey, A.N., 1995. Self-efficacy and relapse to smoking in self-quitters. Addiction 90, 767–772.

Herbst, M., Washburn, A., Stalcup, J., Stalcup, S., Galloway, G., 1996. Mediators and moderators of craving and use. In: Abstracts of the CPDD. San Juan, Puerto Rico, June.

Hernandez-Lopez, C., Farre, M., Roset, P.N., Menoyo, E., Pizarro, N., Ortuno, J., Torrens, M., Cami, J., de La Torre, R., 2002. 3,4-Methylenedioxymethamphetamine (ecstasy) and alcohol interactions in humans: psychomotor performance, subjective effects, and pharmacokinetics. J. Pharmacol. Exp. Ther. 300, 236–244.

Hufford, M.H., Stone, A.A., Shiffman, S., Schwartz, J.E., Broderick, J.E., 2002. Paper vs. electronic diaries: compliance and subject evaluations. Appl. Clin. Trials (August), 38–43.

Jaffe, J.H., Cascella, N.G., Kumor, K.M., Sherer, M.A., 1989. Cocaine-induced cocaine craving. Psychopharmacology 97, 59–64.

Jansen, K.L., 1999. Ecstasy (MDMA) dependence. Drug Alcohol Depend. 53, 121–124.

Johnson, T., Fendrich, M., 2005. Modeling sources of self-report bias in a survey of drug use epidemiology. Ann. Epidemiol. 15, 381–389.

Kosten, T.R., 1992. Pharmacological approaches to cocaine dependence. Clin. Neuropharmacol. 15 (Suppl.), 70A–71A.

Landis, J.R., Koch, G.G., 1977. The measurement of observer agreement for categorical data. Biometrics 33, 159–174.

Lipsitz, S.H., Fitzmaurice, G.M., Orav, E.J., Laird, N.M., 1994a. Performance of generalized estimating equations in practical situations. Biometrics 50, 270–278.

Lipsitz, S.H., Kim, K., Zhao, L., 1994b. Analysis of repeated categorical data using generalized estimating equations. Stat. Med. 13, 1149–1163.

Lipsitz, S.H., Laird, N.M., Harrington, D.P., 1991. Generalized estimating equations for correlated binary data: using the odds ratio as a measure of association. Biometrika 78, 153–160.

Marlatt, G.A., Gordon, J.R., 1985. Relapse Prevention. Guilford Press, New York.

Meyer, R.E., 2000. Craving: what can be done to bring the insights of neuroscience, behavioral science and clinical science into synchrony. Addiction 95 S2, S219–S227.

Miller, M.E., Davis, C.S., Landis, J.R., 1993. The analysis of longitudinal polytomous data: generalized estimating equations and connections with weighted least squares. Biometrics 49, 1033–1044.

Morral, A.R., McCaffrey, D., Iguchi, M.Y., 2000. Hardcore drug users claim to be occasional users: drug use frequency underreporting. Drug Alcohol Depend. 57, 193–202.

Parrott, A.C., 2005. Chronic tolerance to recreational MDMA (3,4-methylenedioxymethamphetamine) or ecstasy. J. Psychopharmacol. 19, 75–87.

Parrott, A.C., Milani, R.M., Parmar, R., Turner, J.D., 2001. Recreational ecstasy/MDMA and other drug users from the UK and Italy: psychiatric symptoms and psychobiological problems. Psychopharmacology (Berlin) 159, 77–82.

Pickens, R., Johanson, C.E., 1992. Craving: consensus of status and agenda for future research. Drug Alcohol Depend. 30, 127–131.

Scholey, A.B., Parrott, A.C., Buchanan, T., Heffernan, T.M., Ling, J., Rodgers, J., 2004. Increased intensity of ecstasy and polydrug usage in the more experienced recreational ecstasy/MDMA users: a WWW study. Addict. Behav. 29, 743–752.

Self, D.W., 1998. Neural substrates of drug craving and relapse in drug addiction. Ann. Med. 30, 379–389.

Shiffman, S., Balabanis, M.H., Paty, J.A., Engberg, J., Gwaltney, C.J., Liu, K.S., Gnys, M., Hickcox, M., Paton, S.M., 2000. Dynamic effects of self-efficacy on smoking lapse and relapse. Health Psychol. 19, 315–323.

Shiffman, S., Gwaltney, C.J., Balabanis, M.H., Liu, K.S., Paty, J.A., Kasse, J.D., Hickcox, M., Gnys, M., 2002. Immediate antecedents of cigarette smoking: an analysis from ecological momentary assessment. J. Abnorm. Psychol. 111, 531–545.

Shiffman, S., Paty, J.A., Gnys, M., Kassel, J.A., Hickcox, M., 1996. First lapses to smoking: within-subjects analysis of real-time reports. J. Consult. Clin. Psychol. 64, 366–379.

Shiffman, S., Stone, A.A., 1998. Introduction to the special section: ecological momentary assessment in health psychology. Health Psychol. 17, 3–5.

Shiffman, S., Waters, A.J., 2004. Negative affect and smoking lapses: a prospective analysis. J. Consult. Clin. Psychol. 72, 192–201.

Simons, J.S., Gaher, R.M., Oliver, M.N., Bush, J.A., Palmer, M.A., 2005. An experience sampling study of associations between affect and alcohol use and problems among college students. J. Stud. Alcohol. 66, 459–469.

Stone, A., Shiffman, S., 1994. Ecological momentary assessment (EMA) in behavioral medicine. Ann. Behav. Med. 16, 199–202.

Stone, A., Shiffman, S., Schwartz, J., Broderick, J., Hufford, M., 2002. Patient compliance with paper diaries. BMJ 324, 1193–1194.

Strote, J., Lee, J.E., Weschsler, H., 2002. Increasing MDMA use among college students: results of a national survey. J. Adol. Health 30, 64–72.

Sudman, S., Bradburn, N.M., Schwarz, N., 1996. Thinking About Answers: The Applications of Cognitive Processes to Survey Methodology. Jossey-Bass, San Francisco.

Tiffany, S.A., 1990. Cognitive model of drug urges and drug-use behavior: role of automatic and nonautomatic processes. Psychol. Rev. 97, 147–168.

Topp, L., Hando, J., Dillon, P., Roche, A., Solowij, N., 1999. Ecstasy use in Australia: patterns of use and associated harm. Drug Alcohol Depend. 55, 105–115.

Topp, L., Barker, B., Degenhardt, L., 2004. The external validity of results derived from ecstasy users recruited using purposive sampling strategies. Drug Alcohol Depend. 73, 33–40.

Verheyden, S.L., Henry, J.A., Curran, H.V., 2003. Acute, sub-acute and long-term subjective consequences of 'ecstasy' (MDMA) consumption in 430 regular users. Hum. Psychopharmacol. 18, 507–517.

Weiss, R., Griffin, M., Hufford, C., 1995. Craving in hospitalized cocaine abusers as a predictor of outcome. Am. J. Drug Alcohol Abuse 21, 289–301.

Winstock, A.R., Griffiths, P., Stewart, D., 2001. Drugs and the dance music scene: a survey of current drug use patterns among a sample of dance music enthusiasts in the UK. Drug Alcohol Depend. 64, 9–17.