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Trends in reported and biologically confirmed drug use among people who use ecstasy in the nightclub/festival-attending population, 2016–2022

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HIGHLIGHTS

- We compared trends in self-reported drug use and drug positivity from 2016 to 2022.
- There were decreases in detection of MDMA, synthetic cathinones and MDA in particular.
- Corrected prevalence of synthetic cathinone and MDA use decreased more than self-report.
- Decreases in drug use/exposure were steeper regarding 'adjusted' prevalence.
- Underreported drug use had less of an effect on prevalence in 2022 than it did in 2016.

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ABSTRACT

Background: Nightclub/festival attendees are a population with high rates of party drug use, but research is needed to determine whether there have been shifts in unintended drug exposure in this population (e.g., via adulterants) to inform prevention and harm reduction efforts.
Methods: Adults entering nightclubs and festivals in New York City were asked about past-year drug use in 2016 through 2022, with a subset providing a hair sample for testing. We focused on the 1943 who reported ecstasy use (of which 247 had a hair sample analyzed) and compared trends in self-reported drug use, drug positivity, and adjusted prevalence (adjusting for unreported use).
Results: MDMA positivity decreased from 74.4 % to 42.3 %, and decreases occurred regarding detection of synthetic cathinones ("bath salts"; a 100.0 % decrease), MDA (a 76.9 % decrease), amphetamine (an 81.3 % decrease), methamphetamine (a 64.2 % decrease), and ketamine (a 33.4 % decrease) (ps $< .05$). Although prevalence of MDA and synthetic cathinone use was comparable between self-report and adjusted report in 2022, gaps in prevalence were wider in 2016 (ps $< .01$). Adjusted prevalence of synthetic cathinone use decreased more across time than prevalence based on self-report (a 79.4 % vs. 69.1 % decrease) and adjusted report for MDA use decreased more than prevalence based on self-report (a 50.6 % vs. 38.9 % decrease).
Conclusions: Combining self-report and toxicology tests helped us determine that decreases in drug use/exposure were steeper regarding adjusted prevalence. Underreported drug exposure—possibly due to exposure to adulterants—appears to have had less of an effect on prevalence in 2022 than it did in 2016.

1. Introduction

Surveys are a common method for assessing and estimating prevalence of drug use. However, an inherent limitation of self-report is that responses may not always be accurate, and there is potential for both intentional and unintentional misreporting of use. While intentional over reporting (e.g., mischievous responding) is sometimes a concern, particularly among adolescents (Furlong et al., 2017; Robinson-Cimpian, 2014), a bigger concern in drug epidemiology studies is underreporting (Fendrich et al., 2004, 2008; Palamar, 2018). Since drug

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use is often seen as a stigmatized behavior, intentional underreporting may occur among people who fear disclosing use (Fendrich et al., 2004). Other individuals may not understand or pay attention to survey questions, or simply forget about use (Le et al., 2021; Palamar, 2018). In general, agreement between self-report and biological test results is high (Bharat et al., 2023); however, when focusing on synthetic drug use, a further complicating factor is that people who use such drugs may unknowingly have been exposed to psychoactive adulterant or contaminant drugs, leading to underreporting of use of those drugs. For example, it is now common for people in the United States (US) who use heroin to be exposed to fentanyl as an adulterant (Bach et al., 2020; Buresh et al., 2019). The party drug, ecstasy, which is typically thought to contain 3, 4-methylenedioxymehtamphetamine (MDMA), historically, has been adulterated with a wide variety of drugs (Parrott, 2004; Tanner-Smith, 2006). In recent years, synthetic cathinones, also known as "bath salts" in the US, have been particular adulterants of concern (Brunt et al., 2011, 2016; Caudevilla-Gálligo et al., 2013; Oliver et al., 2018). Given the constantly shifting landscape of adulterants in drugs such as ecstasy (Brunt et al., 2011, 2016; Vidal Giné et al., 2016), it is important to track trends in potential unknown exposure to such adulterant drugs to inform prevention and harm reduction efforts.

There is a lack of information regarding trends in ecstasy purity in the US. Much of what we know regarding ecstasy purity is limited to research in Europe. There was a known shortage of high-purity MDMA throughout much of the world beginning in about 2008 due to a shortage in safrole, a natural MDMA precursor (European Monitoring Centre for Drugs and Drug Addiction [EMCDDA], 2016a). During this shortage, ecstasy tended to be adulterated or replaced with other novel stimulants such as synthetic cathinones (Brunt et al., 2011, 2016; EMCDDA, 2012; Vidal Giné et al., 2016). However, the market for high-purity ecstasy became revitalized, at least in Europe, in the early 2010s in response to the availability of a new MDMA pre-precursor called PMK-glycidate (EMCDDA, 2016b). High-dose pills became prevalent, particularly throughout Europe (EMCDDA, 2016b). In fact, drug testing in Europe suggested that over half (53 %) of tested ecstasy pills in 2015 contained more than 140 mg of MDMA compared to only 3 % in 2009. In 2020, ecstasy pills in Europe contained an average of 125–200 mg of MDMA, with average purity of ~80 % (EMCDDA, 2022). Within the dance festival scene in Australia in late 2019 and early 2020, only 5 % of ecstasy samples tested contained drugs other than MDMA (O'Reilly et al., 2022). However, ecstasy purity trends in the US do not appear to mirror those in Europe or Australia as in 2015 and 2016 we detected extensive unreported exposure to various synthetic cathinones, methamphetamine, and other novel stimulants among people in New York City (NYC) who used ecstasy (Palamar and Salomone, 2021; Palamar et al., 2016, 2017). Research is needed to investigate patterns of ecstasy use and potential contents of ecstasy in the US, particularly after the onset of the COVID pandemic. Recent estimates suggest that ecstasy use declined during the pandemic and that prevalence of use has not rebounded (Miech et al., 2023; Palamar et al., 2023a; Patrick et al., 2023). A recent study in Australia also estimated a continued decrease in ecstasy consumption since the pandemic along with a decrease in perceived purity (Price et al., 2023). More research is needed to estimate trends in use but also in exposure to adulterant drugs.

While drug checking is the most direct way to determine drug contents prior to use, in the US, there are currently legal and social barriers that often deter or prevent people from testing their drugs (Bardwell et al., 2019; Reed et al., 2021). However, testing people's biospecimens to help determine exposure to adulterant drugs can provide information regarding drugs that have already been consumed (Palamar et al., 2020). In addition, when data are collected via both self-report and biospecimen testing, this provides an opportunity to identify underreported drug use (e.g., drug exposure determined through hair testing that was not reported by the participant) and adjust self-reported prevalence based on toxicology results (Fendrich et al., 2004; Palamar et al., 2021).

In this study, we focused on repeated cross-sectional data collected from adults recruited entering electronic dance music (EDM) events at nightclubs and dance festivals in NYC. We focus on this population because use of party drugs such as ecstasy tend to be highly prevalent (Kelly et al., 2006; Mohr et al., 2020; Palamar et al., 2023a; Ramo et al., 2010), possibly leading those who use to be at unique risk for potential exposure to other drugs as adulterants or contaminants. Indeed, other party drugs (e.g., ketamine, cocaine) can lead to unknown exposure to other drugs (DiSalvo et al., 2021; Palamar, 2023a), but we focus on people who use ecstasy as this is among the most common drugs used in this population. We examined trends in self-reported past-year ecstasy use, and among those reporting use, we examined trends in self-reported use of various other drugs as well as trends in positivity of MDMA and other drugs based on hair testing. We further compared hair test results to self-report across years and adjusted for underreporting among those who tested positive for drug exposure after not reporting use. This allowed us to examine trends in possible unintentional exposure. In light of a lack of drug testing studies focusing on ecstasy use in the US, results can help inform researchers and public health practitioners regarding the potential for unknown exposure to other drugs among people who use ecstasy.

2. Methods

2.1. Procedures

Adults (age $\geq$ 18) were surveyed as they were about to enter randomly selected EDM events (featuring live DJs) at nightclubs in NYC. Specifically, during recruitment weeks, events at nightclubs were randomly selected using R 3.1 software (R Core Team, 2014) based on an ongoing list of events advertised on a popular EDM party ticket website. While most recruitment efforts focused on events held at nightclubs, we also surveyed participants outside of 1–2 large EDM dance festivals each year (but these were not randomly selected as such events are infrequent). Surveys were administered in 2016 (n = 1084), 2017 (n = 958), 2018 (n = 1029), 2019 (n = 1005), 2021 (n = 349), and 2022 (n = 494), with a combined total of 4919 participants surveyed. (The annual sample size was tapered post-COVID onset as the original proposed last year of data collection [2021] was split into two years largely due to staffing and funding). Participants were surveyed entering 225 events—37 in 2016, 39 in 2017, 24 in 2018, 80 in 2019, 23 in 2021, and 22 in 2022, and survey response rates were 77 %, 74 %, 73 %, 65 %, 63 %, and 82 %, respectively (72 % overall).

To determine eligibility, individuals were approached by study staff and asked their age and asked if they were about to attend the event. Surveys were taken on tablets, which typically took about 10 min to complete. Participants were offered compensation of $10 USD. In addition, hair samples were collected from participants surveyed in 2016, 2017, 2019, 2021, and 2022. In 2016–2017, participants were not offered compensation for hair submissions, but beginning in 2019 they were offered an additional $5 USD. Hair submissions were not mandatory as we did not want refusals to affect overall survey result generalizability. In this study, we focused on the 1943 participants who reported past-year ecstasy use. Of these, 26 % provided a hair sample and 49 % of these samples were analyzed (13 % of the full analytic sample; n = 247). In the analytic sample, 90 participants surveyed in 2016 had hair data, and 24, 85, 22, and 26 had hair data from 2017, 2019, 2021, and 2022, respectively. The smaller subsamples providing analyzable hair occurred due to low hair provision response rates and due to constraints in funding that allowed for analysis of collected samples (which shifted during various cross-sections of data collection).

2.2. Hair analysis

Hair samples were tested via published methods using ultra-high performance liquid chromatography–tandem mass spectrometry

(UHPLC-MS/MS) (Di Corcia et al., 2012, 2018). Although, in our analysis of 2021 and 2022 samples, we further utilized untargeted high-resolution mass spectrometry (HRMS)-based screening, which allows for qualitative identification of new psychoactive substances (NPS) not in our library (Salomone et al., 2021). We set the limits of detection as the minimum criterion to identify positive samples because we aimed to detect any amount of drug exposure (e.g., including exposure via adulterants or contaminants). However, given that 3,4-methylinedioxy-amphetamine (MDA) is a metabolite of MDMA, based on past research, we conservatively estimated MDA use for cases in which the ratio of MDA ng/mg to MDMA ng/mg was ≥ 0.2 (Kunsman et al., 1996; Rothe et al., 1997). Detection above this threshold was conservatively estimated to indicate external MDA exposure as opposed to MDA detection resulting from MDMA metabolization. Hair was analyzed in its full length up to 12 cm which represents a rough 12-month timeframe assuming normal hair growth of about 1 cm per month (Kintz et al., 2015). The average length of hair analyzed was 7.5 cm (SD = 3.8, median = 7) with 30.0 % being the full 12 cm and 63.2 % being at least 6 cm. In this analysis, we focused on detection of MDMA, ketamine, amphetamine, MDA, methamphetamine, and synthetic cathinones. We focused specifically on these drugs because we consistently tested for exposure throughout the entire study time period. Targeted analysis focusing on synthetic cathinones included α-PVP, 3,4-MDPV, butylone, methylone, ethylone, pentylone, *N*-ethylpentilone, ethcathinone, 4F-methcathinone, 3,4-DMCC, mephedrone, buphedrone, pentedrone, methedrone, mexedrone, and naphyrone. However, as aforementioned, in samples collected in 2021 and 2022, untargeted analysis allowed for detection of newer synthetic cathinones.

2.3. Statistical analysis

First, we calculated descriptive statistics to describe sample characteristics. Specifically, for both the full survey sample and the analytic sample (reporting past-year ecstasy use), we calculated percentages to describe the distribution of survey year, participant sex, age, race/ethnicity, education, and recruitment venue type (nightclub vs. festival). Among those reporting ecstasy use, we also compared percentages according to who did versus who did not provide an analyzable hair sample, and chi-square was used to test for potential differences in prevalence. The rest of the analyses were limited to those reporting past-year ecstasy use.

We calculated descriptive statistics to determine the prevalence of use of each drug (each year). First, we examined the trend of self-reported ecstasy use in the full recruited sample and then all following trends were limited to those reporting ecstasy use. Specifically, we calculated the prevalence of drug positivity (among those providing an analyzable hair sample), prevalence as per self-report (for the full analytic sample), and adjusted prevalence in which positive detection without self-reported use was coded as use (also for the full analytic sample). We did not consider reporting use and not testing positive as overreporting, however, because research has found that overreporting tends to be more of an adolescent phenomenon (Furlong et al., 2017; Robinson-Cimpian, 2014) and not all use can be detected (especially if a shorter hair sample was submitted). We then used three methods to examine trends with each method using multivariable logistic regression controlling for participant sex, age, race/ethnicity, education, and recruitment venue type. First, we fit an indicator for each year (with 2016 as the comparison) to determine whether there was a significant difference in prevalence between 2022 and 2016. Next, we examined trends in use of each drug by estimating log-odds of use as a linear, quadratic, and cubic function of time (year) as a continuous predictor. Year was coded as 0, 1, 2, 3, 5, and 6 for 2016, 2017, 2018, 2019, 2021, and 2022, respectively (which accounted for no data in 2020). Finally, with respect to trends, we determined whether there was a significant change in prevalence after the onset of COVID (2021–2022) compared to pre-COVID years (2017–2019) by examining this as a binary indicator variable. We also compared the prevalence of underreporting in 2016 and 2022 using Fisher's Exact Test (with a null hypothesis of no difference in underreporting between years). Data were analyzed using Stata 17 SE (StataCorp, 2021) and R 4.2.2 (R Core Team, 2022). Study methods were approved by the New York University Langone Medical Center institutional review board.

3. Results

Characteristics of the study sample are presented in Table 1. Among those reporting past-year ecstasy use (the analytic sample, n = 1943), the majority were male (60.0 %), age ≥ 26 (52.4 %), white (56.7 %), and had a bachelor's degree or higher (64.3 %). Among participants who reported ecstasy use, females were more likely to provide an analyzable hair sample than males ($p = .017$) and those surveyed at nightclubs were more likely than those surveyed at festivals ($p = .002$). Further, a significantly smaller percentage of hair samples were collected in 2017 than in other years ($p < .001$).

Trends in prevalence of positive drug detection among people reporting past-year ecstasy use are presented in Table 2 and in Fig. 1. Between 2016 and 2022, MDMA positivity decreased from 74.4 % to 42.3 % ($p < .001$), and decreases were also estimated for detection of synthetic cathinones (a 100.0 % decrease; linear trend $p < .001$), MDA (a 76.9 % decrease, $p = .010$), amphetamine (an 81.3 % decrease, $p =$

Table 1
Sample characteristics.

	Full Sample	Participants Reporting Past-Year Ecstasy Use		
	All Participants Surveyed	Analytic Study Sample	Provided an Analyzable Hair Sample	
	(N = 4919) n (%)	(n = 1943) n (%)	No (n = 1275) n (%)	Yes (n = 247) n (%)
Year				
2016	1084 (22.0)	468 (24.1)	378 (29.7)	90 (36.4)[c]
2017	958 (19.5)	353 (18.2)	329 (25.8)	24 (9.7)
2018	1.029 (20.9)	421 (21.7)	—	—
2019	1005 (20.4)	409 (21.1)	324 (25.4)	85 (34.4)
2021	349 (7.1)	124 (6.4)	102 (8.0)	22 (8.9)
2022	494 (10.0)	168 (8.7)	142 (11.1)	26 (10.5)
Sex				
Male	2722 (55.3)	1166 (60.0)	1035 (61.0)	131 (53.0)[a]
Female	2197 (44.7)	777 (40.0)	661 (39.0)	116 (47.0)
Age (years)				
18–25	2458 (50.0)	925 (47.6)	779 (47.1)	126 (51.0)
≥ 26	2461 (50.0)	1018 (52.4)	897 (52.9)	121 (49.0)
Race/Ethnicity				
White	2578 (52.4)	1102 (56.7)	946 (55.8)	156 (63.2)
Black	384 (7.8)	101 (5.2)	92 (5.4)	9 (3.6)
Hispanic	891 (18.1)	331 (17.0)	289 (17.0)	42 (17.0)
Asian	655 (13.3)	240 (12.4)	215 (12.7)	25 (10.1)
Other/Mixed	411 (8.4)	169 (8.7)	154 (9.1)	15 (6.1)
Education				
High School or Less	672 (13.7)	224 (11.5)	196 (11.6)	28 (11.3)
Some College	1204 (24.5)	470 (24.2)	407 (24.0)	63 (25.5)
Bachelor's Degree	2300 (46.8)	948 (48.8)	832 (49.1)	116 (47.0)
Graduate School	743 (15.1)	301 (15.5)	261 (15.4)	40 (16.2)
Where Surveyed				
Nightclub	3765 (76.5)	1502 (77.3)	1292 (76.2)	210 (85.0)[b]
Dance Festival	1154 (23.5)	441 (22.7)	404 (23.8)	37 (15.0)

Note. We did not collect hair samples in 2018.[a] $p < .05$
[b] $p < .01$
[c] $p < .001$.

Table 2
Trends in positive detection of drugs among people reporting ecstasy use, 2016–2022 ($n = 247$)[b].

	Prevalence				Trend Tests (p-value)		
	2016 n (%)	2022 n (%)	Absolute Change %	Relative Change %	2022 vs. 2016	Trend	Pre- vs. Post-COVID Onset
MDMA	67 (74.4)	11 (42.3)	−32.1	−43.1	< .001	.039[c]	< .001
Ketamine	52 (57.8)	10 (38.5)	−19.3	−33.4	.049	.004[c]	.002
Amphetamine	37 (41.1)	2 (7.7)	−33.4	−81.3	.018	.005[c]	.003
MDA	30 (33.3)	2 (7.7)	−25.6	−76.9	.010	.002[a]	.002
Methamphetamine	29 (32.2)	3 (11.5)	−20.7	−64.2	.045	.001[a]	.108
Synthetic Cathinones	25 (27.8)	0 (0.0)	−27.8	100.0	—	< .001[a]	.020

Note. There were 91 participants who had hair tested in 2016 and 26 in 2022. Absolute % change is the difference between prevalence in 2022 and 2016. Relative % change is the ratio of absolute change between 2022 and 2016 and this was calculated as follows: (absolute % change / 2016 prevalence) * 100. The linear trend column focuses on shape of trend detected and we report the p-value for the highest polynomial detected:.

[a] linear trend.

[b] quadratic trend.

[c] cubic trend. "—" indicates that the statistic could not be computed due to constant value (0 %) in 2022.

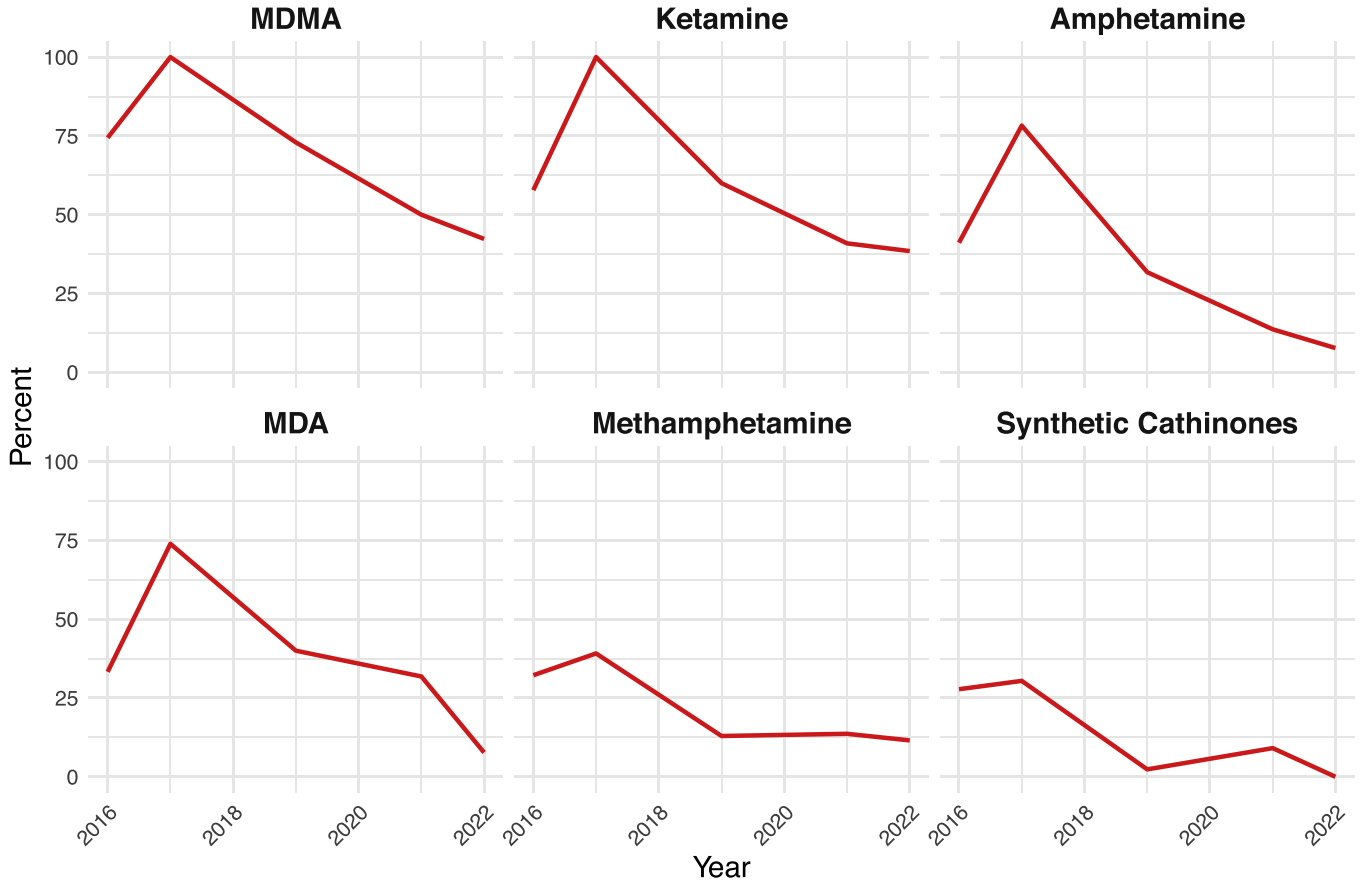

Fig. 1. Trends in Drug Positivity, 2016–2022. Results indicate the percentage of participants who reported ecstasy use in the past year testing positive for each drug.

.018), methamphetamine (a 64.2 % decrease; $p == .045$), and ketamine (a 33.4 % decrease; $p == .049$). Detection of all drugs other than methamphetamine significantly decreased after the onset of COVID (ps < 0.05).

Among the full study sample (including those not reporting ecstasy use), reported past-year ecstasy use decreased between 2016 and 2022 from 43.2 % ($n = 468$) to 34.5 % ($n = 168$; a 20.1 % relative decrease; $p == .001$). Table 3 and Fig. 2 compare trends in prevalence (among those reporting past-year ecstasy use) based on self-reported drug use to adjusted prevalence of use based on toxicology results. Prevalence of ketamine use based on self-report and on adjusted report increased by 28.3 % and 20.6 %, respectively (ps $< .05$) with both increasing in a linear manner (ps $< .01$) and self-report increasing after the onset of COVID ($p == .004$). Prevalence of amphetamine use based on self-report and on adjusted report did not significantly decrease from 2016 to 2022 although a quadratic decrease and a decrease after the onset of COVID was detected (ps $< .05$). With respect to MDA use, despite a 38.9 % decrease in reported use and detection of a significant downward linear trend ($p == .017$), this was not a significant overall decrease. However, adjusted prevalence decreased by 50.6 % ($p == .026$) and this was a quadratic decrease ($p == .002$). The increase in prevalence (from reported to adjusted) of 3.0 % in 2016 was significantly different from the increase in prevalence in 2022 (0.0 %; $p == .026$). Regarding methamphetamine use, no significant trends were detected despite a 28.3 % decrease in use based on self-report and on a 39.2 % decrease in adjusted prevalence. The difference in adjusted prevalence (11.8 %) compared to

Table 3
Comparison of trends of self-reported drug use and adjusted prevalence of drug use among people reporting ecstasy use, 2016–2022[c].

	Prevalence				Trend Tests (p-value)		
	2016 n (%)	2022 n (%)	Absolute Change %	Relative Change %	2022 vs. 2016	Trend	Pre- vs. Post-COVID Onset
Ketamine							
Self-Report	147 (31.4)	68 (40.3)	8.9	28.3	.010	.001[a]	.004
Adjusted	164 (35.0)	71 (42.3)	7.2	20.6	.038	.006[a]	.105
Difference	17 (3.6)	3 (2.0)	−1.6	−44.4			
Amphetamine							
Self-Report	146 (31.2)	43 (25.6)	−5.6	−17.9	.293	.353	.290
Adjusted	162 (34.6)	44 (26.2)	−8.4	−24.4	.125	.001[b]	.025
Difference	16 (3.4)	1 (0.6)	−2.8	−82.4			
MDA							
Self-Report	60 (12.8)	13 (7.8)	−5.0	−38.9	.161	.017[b]	.487
Adjusted	74 (15.8)	13 (7.8)	−8.0	−50.6	.026	.002[b]	.706
Difference	14 (3.0)[d]	0 (0.0)	−3.0	−100.0			
Methamphetamine							
Self-Report	35 (7.5)	9 (5.4)	−2.1	−28.3	.763	.912[a]	.200
Adjusted	55 (11.8)	12 (7.1)	−4.6	−39.2	.355	.401[a]	.130
Difference	20 (4.3)	3 (1.7)	−2.6	−60.5			
Synthetic Cathinones							
Self-Report	36 (7.7)	4 (2.4)	−5.3	−69.1	.062	.032[a]	.080
Adjusted	54 (11.5)	4 (2.4)	−9.2	−79.4	.004	< .001[a]	.014
Difference	18 (3.8)[d]	0 (0.0)	−3.8	−100.0			

Note. Rows labeled as "difference" indicate the difference in percentage between adjusted self-report (considering detected exposure as use) and self-report. Detection of MDA exposure was only considered unintentional exposure if the ratio of MDA to MDMA was > 0.2 ng/mg. Cases exceeding 0.2 in light of no reported use were thus considered adjusted. "–" indicates that relative percentage change could not be computed due to one value having a prevalence of 0. Absolute % change is the difference between prevalence in 2022 and 2016. Relative % change is the ratio of absolute change between 2022 and 2016 and this was calculated as follows: (absolute % change / 2016 prevalence) * 100. The linear trend column focuses on shape of trend detected and we report the p-value for the highest polynomial detected:.

[a] linear trend.
[b] quadratic trend.
[c] cubic trend.
[d] Fisher's Exact Test comparison of underreporting in 2016 vs. 2022 $p < .01$.

prevalence based on self-report (7.5 %) was also not significant (a 4.3 % difference, $p == .157$). Finally, the largest decreases in prevalence were self-reported and adjusted prevalence of synthetic cathinone use (with 69.1 % and 79.4 % decreases, respectively). Adjusted prevalence decreased between 2016 and 2022 ($p == .004$) and this was a linear decrease ($p < .001$) and there was a clear decrease after the onset of COVID. The decrease in self-reported synthetic cathinone use only approached significance ($p == .062$), although the decrease was linear ($p == .032$). The increase in prevalence (from reported to adjusted) of 3.8 % in 2016 was significantly different from the increase in prevalence in 2022 (0.0 %; $p == .006$).

4. Discussion

In this study, we examined trends in past-year drug use among people in the nightclub and festival-attending populations who use ecstasy. This was examined according to self-report, and for a subsample, we were able to include toxicology testing to better understand underreporting of various drugs, which could indicate unintentional exposure. Among people who use ecstasy in this population, for most drugs examined, we detected decreases in both self-reported use and in biologically confirmed use.

Prevalence of past-year ecstasy use decreased in this EDM venue-attending population overall, and among people who reported use of ecstasy in the past year, detection of MDMA exposure substantially decreased. This may suggest increasing use of other drugs purported to be ecstasy/MDMA. Prevalence of detection of amphetamine, MDA, methamphetamine, and synthetic cathinones also decreased among people who use ecstasy, although self-reported use of most of these drugs decreased as well. These decreases corroborate other studies that have found decreases in use of psychostimulants such as ecstasy and amphetamine since the onset of COVID (Miech et al., 2023; Patrick et al., 2023; Price et al., 2022, 2023) and studies finding decreases in both self-reported use and positivity in the full EDM event-attending population (Palamar et al., 2023a; Palamar and Salomone, 2023). The main exception in this study was ketamine in which both reported and adjusted use increased through 2022 despite detected positivity decreasing. National indicators suggest that ketamine seizures and poisonings have been increasing in the US (Palamar et al., 2022, 2023b) so use among some populations may in fact be increasing. It is unknown why ketamine positivity has been decreasing despite an increase in reported (and adjusted) prevalence, but we believe unknown exposure to ketamine in earlier years, perhaps as an adulterant, could have partially driven such a shift. Historically, ecstasy has been adulterated with a wide variety of drugs including ketamine (Parrott, 2004; Tanner-Smith, 2006). Use of a relatively new party drug called Tusi could have also led to underreported ketamine use as not everyone who uses this drug concoction knows that it usually contains ketamine (Palamar, 2023a). We do not believe overreporting was an issue as this tends to be more of an adolescent phenomenon (Furlong et al., 2017; Robinson-Cimpian, 2014), although it is possible that unintentional over-reporting occurred, in which participants believed a drug contained ketamine, but it did not. More research is needed, and with prescribed ketamine (and esketamine) becoming more popular in the US for therapeutic reasons, future work may also need to determine whether or not ketamine was prescribed.

When comparing trends, adjusted prevalence was not remarkably higher than trends based solely on self-report, which suggests that while indeed underreported exposure occurred, such instances did not dramatically increase adjusted prevalence. Regardless, there were two clear differences between prevalence based on self-report and via adjusted prevalence detected for use of MDA and synthetic cathinones. Specifically, we detected significant differences in prevalence in 2016 but not in 2022—suggesting higher levels of underreporting of use of these drugs in 2016. It is unknown whether such underreported use was intentional or due to unknown exposure via adulterants, but previous work suggests that people who use ecstasy, historically, have been at high risk for unintentional exposure to such drugs, with MDA being a

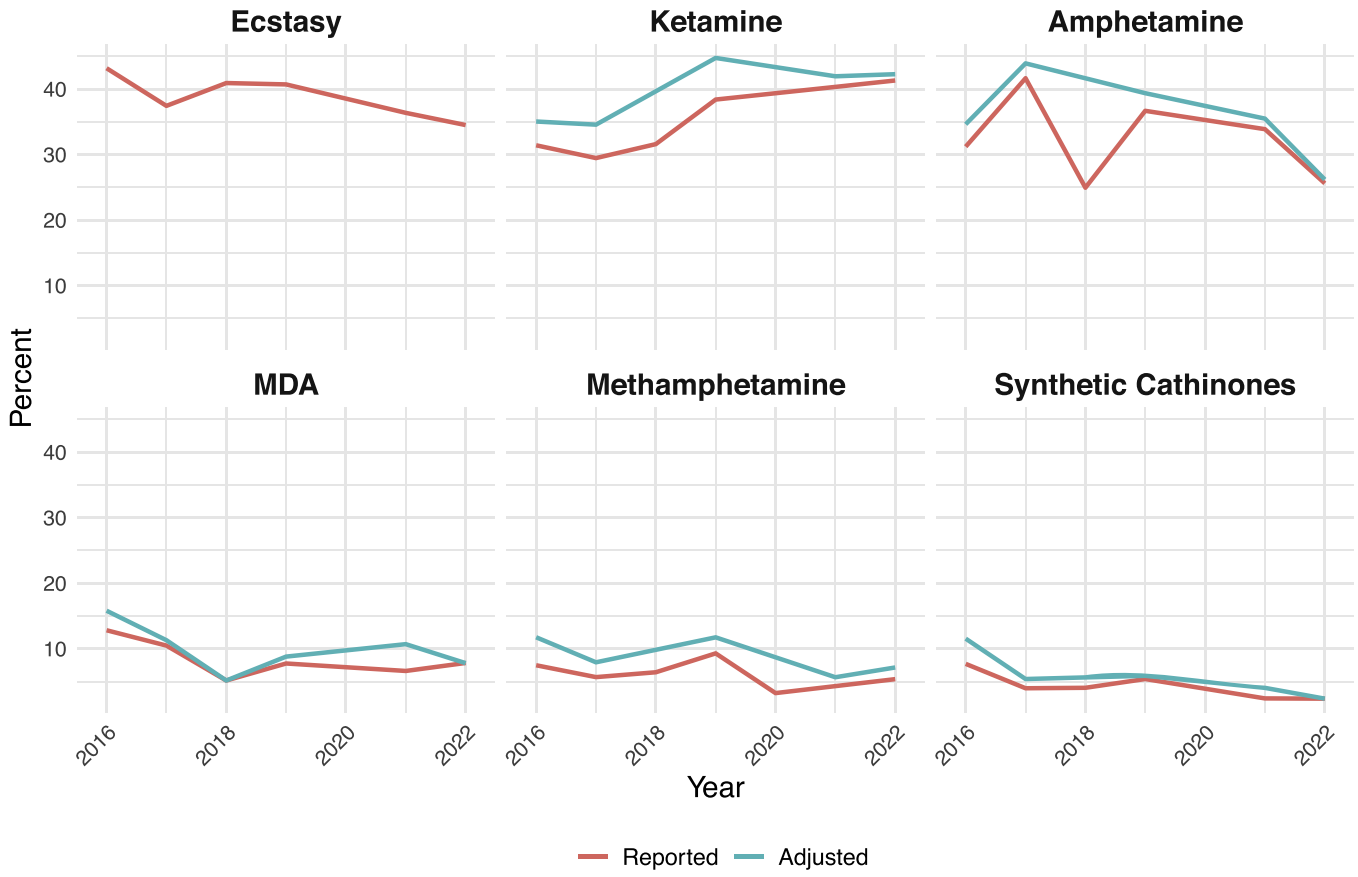

Fig. 2. Trends in Self-Reported Drug Use and in Adjusted Report of Drug Use (Based on Drug Detection), 2016–2022. The trend in ecstasy use is relative to the full recruited sample and trends in other drug use are within those reporting past-year ecstasy use. Results indicate the prevalence (percentage) of participants 1) reporting past-year use of the drug, and 2) reporting use or testing positive for exposure to the drug (adjusted prevalence).

common adulterant for decades (Brunt et al., 2011, 2016; Palamar and Salomone, 2021; Palamar et al., 2016, 2017; Parrott, 2004; Tanner--Smith, 2006; Vidal Giné et al., 2016).

These results may suggest that potential unknown exposure to adulterant drugs via ecstasy or other drug consumption in this population has decreased in recent years, at least regarding unknown exposure to MDA and synthetic cathinones. More research is needed to determine whether such recent shifts are related to increases in MDMA purity (meaning fewer adulterated batches), or to more careful consumption (e.g., a greater portion of people testing their drugs in order to avoid using adulterant drugs). With fears that cocaine in NYC can be adulterated with fentanyl (Allen et al., 2020; Palamar, 2023b), people who use recreational synthetic drugs in general may be becoming more vigilant about testing drugs before use. Although there is a lack of data on trends in drug checking and it is unknown whether such individuals are testing for a variety of drugs or only for fentanyl.

Shifts in synthetic cathinone adulteration of ecstasy likely also play a large part in decreasing trends in unknown exposure to adulterants. After availability of unadulterated ecstasy decreased throughout much of the world from about 2008 through the early 2010s, purity of ecstasy rebounded by about 2012, at least in Europe (Brunt et al., 2011, 2016; EMCDDA, 2012; Vidal Giné et al., 2016). However, trends in increased purity in the US do not appear to mirror those in Europe as synthetic cathinones remained a common adulterant in ecstasy in the US well into the 2010s (Palamar and Salomone, 2021; Palamar et al., 2016, 2017). Although, in this study, we detected a substantial drop in underreported synthetic cathinone use between 2016 and 2022. This might suggest less unknown exposure as adulterants and a lag in shifts of adulteration behind Europe.

It is noteworthy that synthetic cathinones on the illicit market have shifted since 2016. It appears that a large portion of use in the 2010s was due to unknown exposure through drugs like ecstasy (Oliver et al., 2018). Some earlier compounds in this class—particularly methylone—was a common adulterant in ecstasy, in part, due to it having effects similar to MDMA (Poyatos et al., 2023). However, synthetic cathinone availably has drastically shifted since then. For example, in 2016, methylone was still among the most frequently seized synthetic cathinones in the US (US Drug Enforcement Administration [DEA], 2017). Focusing on the top 16 phenethylamine and other stimulant submissions reported in annual DEA seizure reports, between 2016 and 2021, not only did the number of synthetic cathinones appearing in the top 16 stimulant drugs increase from seven to nine, but the total number of submissions (indicating number of seizures) increased from 6964 (2.0 % of stimulant submissions) in 2016 to 14,969 (3.4 %) in 2021 (US DEA, 2017, 2022). It further appears that some of these newer synthetic cathinones appear to now be more common adulterants in drugs other than ecstasy, as co-use trends (based on data from overdose deaths) suggest that deaths involving eutylone (the most-seized synthetic cathinone in 2021) (US DEA, 2022) most commonly involved fentanyl use (77.3 %), and use of cocaine or methamphetamine (53.1 %) (Gladden et al., 2022). However, mortality statistics cannot not generalize to prevalence of use. Eutylone exposure has indeed been linked to ecstasy use (Krotulski et al., 2018, 2021), but poison data now suggest that eutylone has already been largely replaced with *N,N*-dimethylpentylone (Fogarty et al., 2023; NPS Discovery, 2023). More research is needed to systematically test and compare the contents of various drugs to determine the extent to which these new drugs are adulterants in ecstasy as well as in other drugs.

The simultaneous decrease in MDMA detection and in under-reporting of common adulterant drugs might indicate lower purity ecstasy in the US, but at the same time less adulteration, at least with other psychoactive drugs. However, all participants were surveyed in NYC, and while our 2022 results are fairly recent, we must keep in mind that there may be different trends in 2023. For example, recent 2023 data from some US cities suggests that methamphetamine is now commonly pressed in pill form to resemble ecstasy (Washington/Baltimore HIDTA Investigative Support Center, 2023). Continued surveillance is needed to monitor drug purity in this population, particularly in the US.

4.1. Limitations

Results of this study may not be generalizable to other populations although they can help inform knowledge about the potential for exposure to adulterants among people in the general population who use ecstasy. While hair testing can detect exposure to drugs up to a year post-consumption, our ability to detect depends on the length of hair submitted by participants. Hair shorter than 12 cm in particular can lead to under-detection. Further, drug use 1–2 weeks prior to collection typically cannot be detected. Significant differences according to who provided an analyzable hair sample were identified with regard to sex and where participants were surveyed, and this could further bias results. We limited these analyses to six major drugs or drug categories as they were most prevalent (which allowed for trend analysis) but also because we did not have data on exposure to all major drugs (e.g., cocaine) in earlier years. We did test for additional NPS including fentanyl and its analogs in later years, but the few cases of detection did not allow us to examine trends with confidence. However, even for drugs of focus, our results do not directly confirm that underreported use was linked directly to ecstasy use as unknown exposure could also have occurred from use other synthetic drugs. In addition, since MDA is a metabolite of MDMA, it is difficult to deduce whether detection is related to metabolization of MDMA or to unintentional exposure (or both). In this analysis, we conservatively deemed cases with a ratio of MDA to MDMA exposure (ng/mg) of $\geq$ 0.2 to be likely unknown external MDA exposure. Regarding amphetamine use, we asked only about nonmedical use, so it is possible that adjusted prevalence considering positive toxicology results led to over-adjustment in situations if the drug (e.g., Adderall) was only used medically. Finally, it is important to note that we were only able to hair-test a portion of people in this population. Requiring a hair submission would bias overall findings based on self-report; however, it is unknown how those who refused to provide a hair sample biased overall results. Similar largescale epidemiology studies were only able to focus on $<$ 10 % of hair samples collected (Wade et al., 2023). Relatively small subsample sizes of participants providing an analyzable hair sample (particularly in later years), and smaller survey sample sizes in general, is also a limitation as this can affect generalizability of results.

4.2. Conclusion

Among nightclub and festival attendees in NYC, ecstasy use has decreased, and among people who use ecstasy, use of other drugs such as amphetamine, MDA, and synthetic cathinones have decreased. Ketamine use, however, has increased, despite decreases in detected use. Results suggest that there were larger gaps in underreporting of MDA and synthetic cathinone use in 2016 compared to 2022, possibly suggesting that unknown or unintentional exposure to these drugs (possibly as adulterants in ecstasy or other drugs) has decreased. Future research is needed to determine whether shifts in unreported use are due to changing drug supply (e.g., higher purity ecstasy) or more careful use (e.g., using drug checking) to ensure use of higher purity drugs. Relatedly, research is needed to determine to what extent trends in drug exposure in this population can inform trends in the general population.

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CRediT authorship contribution statement

Joseph J. Palamar: Conceptualization, Data curation, Formal analysis, Funding acquisition, Writing – original draft, Writing – review & editing. **Alberto Salomone:** Formal analysis, Supervision, Funding acquisition, Writing – original draft, Writing – review & editing. **Marta Massano:** Formal analysis, Writing – original draft, Writing – review & editing. **Charles M. Cleland:** Formal analysis, Supervision, Funding acquisition, Writing – original draft, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare no conflicts of interest.

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