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## **Using quantitative wastewater analysis to measure daily usage of conventional and emerging illicit drugs at an annual music festival**

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## **Abstract**

### Introduction and Aims

Wastewater analysis provides a non-intrusive way of measuring drug use within a population. We used this approach to determine daily use of conventional illicit drugs [cannabis, cocaine, methamphetamine and 3,4-methylenedioxymethamphetamine (MDMA)] and emerging illicit psychostimulants (benzylpiperazine, mephedrone and methylone) in two consecutive years (2010 and 2011) at an annual music festival.

### Design and Methods

Daily composite wastewater samples, representative of the festival, were collected from the on-site wastewater treatment plant and analysed for drug metabolites. Data over 2 years were compared using Wilcoxon matched-pair test. Data from 2010 festival were compared with data collected at the same time from a nearby urban community using equivalent methods.

### Results

Conventional illicit drugs were detected in all samples whereas emerging illicit psychostimulants were found only on specific days. The estimated per capita consumption of MDMA, cocaine and cannabis was similar between the two festival years. Statistically significant ( $P < 0.05$ ;  $Z = -2.0$ – $2.2$ ) decreases were observed in use of methamphetamine and one emerging illicit psychostimulant (benzyl piperazine). Only consumption of MDMA was elevated at the festival compared with the nearby urban community.

### Discussion and Conclusions

Rates of substance use at this festival remained relatively consistent over two monitoring years. Compared with the urban community, drug use among festival goers was only elevated for MDMA, confirming its popularity in music settings. Our study demonstrated that wastewater analysis can objectively capture changes in substance use at a music setting without raising major ethical issues.

It would potentially allow effective assessments of drug prevention strategies in such settings in the future.

Keywords: consumption pattern; substance misuse; sewage epidemiology; Australia

## Introduction

Surveys have demonstrated that music event attendees consume illicit substances more frequently than similar age cohorts in the general community [1-3]. This makes such events an opportune place to monitor illicit drug use in a population at higher risk of substance-related harm [2, 4-6].

Most previous studies have used cross-sectional surveys to measure drug use among music event attendees [2, 3, 7, 8]. While these surveys provide important person-centric information, they may be subject to errors arising from reporting biases and low response rates. Additionally, attendees may not be able to accurately identify or recall substances they have consumed, such as the exact chemical content of pills or capsules. Analysis of urine or saliva provide alternatives to self-report data [4] but patrons may be unwilling to provide samples due to intrusiveness or fear of prosecution, and this type of testing also requires substantial resources.

Wastewater analysis is an alternative method of monitoring population drug use by measuring excreted drug residues in raw wastewater. The method provides an objective and non-intrusive way of measuring drug consumption in the population contributing to a sewer catchment. The method also protects individual anonymity because samples are collected from pooled and intermingled wastewater, avoiding potential ethical issues arising from identifying urine samples of individual drug users [9]. It has been demonstrated that data from wastewater analysis can be an effective complement to traditional epidemiological methods for studying illicit drug use (e.g. [10-12]). The method was initially applied in general communities to estimate consumption of the more conventional illicit drugs, such as cocaine, amphetamines, ecstasy, cannabis and heroin (e.g. [10, 13-15]). Since then, its application has extended to monitoring drug use in specific facilities, such as prisons [16], schools [17] and sporting events [18].

The availability of suitable analytical techniques and pharmacokinetic data has made it comparatively easy to estimate consumption of these commonly used illicit drugs. It is a significant challenge to assess the use of emerging psychoactive substances, also known as 'legal highs', 'bath salts' or 'research chemicals'. The 2010 Australian Ecstasy and Related Drug Reporting System (EDRS) found that one third of frequent ecstasy users reported using emerging psychoactive substances of stimulant or psychedelic classes in the preceding 6 months [19]. These new substances can be sold alone or used as agents mixed with conventional drugs. For instance, recent analyses of 'ecstasy' tablets seized by Australian law enforcement agencies found that some contained mephedrone, benzyl piperazine as well as 3,4-methylenedioxymethamphetamine (MDMA) [19, 20]. The short history of these new substances means that their long-term adverse effects on human health are not yet known. Also, the use of these drugs is often not included in general household surveys, hospital records, ambulance or treatment service data.

Markets for new illicit substances can expand quickly, particularly in music settings where patrons appear to be willing to experiment with new substances, such as mephedrone [21]. Also, in the EDRS survey, users reported that they usually consumed emerging psychoactive substances in music venues [22]. This suggests that monitoring new drug use at music events may provide a useful early warning system before use of these drugs becomes more widespread in the community.

Furthermore, music settings often attract adolescents and young adults, a sub-population that may be under-represented in national drug use monitoring systems as ethical constraints and/or sampling methods often produces low response rates in these age groups and large confidence intervals around estimates of use for those below 20 years old [23-25].

This study used samples collected from a wastewater treatment plant serving a music festival, to: (i) estimate the daily use of conventional and emerging illicit substances at an annual music festival; (ii) assess changes in use over two consecutive years; and (iii) compare the data on drug use in the music festival with that in a nearby urban community.

## Methods

### Setting

The festival we studied is held annually during summer in Australia. Music is central to the festival but there are also multi-cultural performances, visual arts, crafts workshops and guest speakers. Therefore, the festival has a different ethos to music events such as dance festivals or 'rock' concerts; children are welcome and special provisions are made for attendees with physical disabilities. This study included the 2010 and 2011 festivals.

Based on ticket sales, the number of daily attendees was 15 300–19 700 (average 16 700; SD 1680) in 2010 and 12 100–17 100 (14 700; 1890) in 2011 (Table 1). The festival organiser managed to survey the age of attendees, showing that the festival attracts people of all ages (Table 1), and there was no significant difference in attendee demographics between the two festival years. About one-third of attendees were 18–29 years old, making it the largest age group in both years. The age groups of 6–17, 30–39, 40–49 and 50–59 each accounted for about a sixth of the total attendees. The 60+ age group accounted for about 5% to 6% of attendees. Tickets were not needed for patrons younger than six years so there are no data on the number of attendees in this age range.

	Music festivals		Urban areas [26]
Ages	2010	2011	2010
6–17	13.7	15.8	5.0
18–29	32.2	34.5	22
30–39	16.7	15.8	17
40–49	15.3	14.5	17
50–59	16.1	14.5	15
60+	6.0	5.0	24
Total population size	~100 000	~88 600	~350 000

Table 1. Age profiles of the music festival and nearby urban area (%)

### Wastewater sampling

The onsite wastewater treatment plant (WWTP) only received wastewater from the festival. Raw wastewater samples were obtained at the WWTP's inlet with the festival organisers' consent. Representative daily composite samples were collected under refrigeration (4°C) using a continuous flow-proportional sampling side stream. In 2010, a technical problem prevented the sampling device from being controlled by wastewater flow; consequently, a constant continuous sampling side stream was used. This was still adequate and did not lead to any systematic variations because the results of two hourly composite samples showed that there was no correlation between the chemical concentrations and the flows (Supporting Information Figure S1). The samples were preserved on site, using 2 M hydrochloride acid and frozen until analysis. This commonly applied sampling procedure has been demonstrated to maintain the stability of target compounds in wastewater (e.g. [14, 27-31]).

#### Chemical analyses

A total of 13 drug residues (i.e. parent drugs and/or its key metabolites) were analysed. These included the conventional illicit drugs: MDMA, 11-nor-9-carboxy- $\Delta^9$ -tetrahydrocannabinol (THC-COOH), amphetamine, benzoylecgonine, cocaine and methamphetamine, and the emerging illicit psychostimulants: benzyl piperazine, mephedrone and methylone.

Details of the sample preparation process and instrumental analysis have been reported previously [28]. Briefly, samples were filtered and spiked with corresponding mass-labelled chemical standards for compensating matrix effects, chemical losses during sample preparation and instrumental variability. Except for THC-COOH, no sample extraction was necessary before instrumental analysis. Due to its relatively low concentrations, THC-COOH in the filtered samples was solid-phase extracted onto preconditioned Oasis® MCX cartridges (Waters, Milford, MA, USA) and then eluted with methanol. The selected drug residues in the filtered samples and the extracts were analysed and quantified using liquid chromatography (Shimadzu Nexera UHPLC system, Kyoto, Japan) coupled with tandem mass spectrometry (AB SCIEX QTRAP®5500, Ontario, Canada). The instrumental conditions to measure all the targeted drug residues followed the previously developed analytical method with an additional optimisation of mass spectrometry for the emerging illicit psychostimulants in this study (Supporting Information Table S1).

#### Back estimation of drug mass loads and doses

The back-calculation steps have been previously described and widely applied in the literature (e.g. Zuccato et al. and Postigo et al. [10, 15, 32]). Basically, a mass load of a drug residue is obtained by multiplying measured concentrations with total wastewater flows. The estimated mass load is then corrected by both the excretion fraction and the molecular mass ratio between the parent drug and its metabolite (Supporting Information Table S2) to estimate the consumed mass of the parent drug. For the conventional illicit drugs, the number of doses is estimated by dividing this quantity by a standard dose (Supporting Information Table S3) (details in Prichard et al. [13] and Lai et al. [33]). The data are normalised to the daily number of attendees.

As there was little or no input from greywater sources onsite, the raw wastewater was concentrated with human wastes only. Microbial degradation and hydrolysis of the targeted chemicals in the wastewater could be pronounced together with the high temperature during summer. For this reason, cocaine consumption was estimated from both unchanged cocaine and cocaine-equivalent benzoylecgonine. A similar approach has been recently suggested to eliminate estimation errors arising from the transformation of cocaine in sewer systems [34]. When estimating illegal methamphetamine consumption, we assumed that prescription medications which are metabolised

to methamphetamine (i.e. selegiline) and dexamphetamine were not present in significant quantities, primarily because selegiline is mainly used to treat persons with Parkinson's disease who are unlikely to attend the festival in large numbers [35]. Dexamphetamine medication is less often used after the late teens [36-38]. Similarly, it is unlikely that illegal amphetamine use distorted the back-calculation of methamphetamine use because of low usage levels in Australia [20] (details in Prichard et al. [13]). Like cocaine, methamphetamine consumption was aggregated from both the load of methamphetamine and methamphetamine-equivalent amphetamine. Consumption of MDMA and cannabis was back-estimated from single measurement, specifically MDMA itself and THC-COOH, respectively.

#### Comparison with community levels of substance use

Extent of use of the conventional illicit drugs at the 2010 festival was compared with that in a nearby urban area (~350 000 people; see Table 1 for demographic details) during the same time period using consistent sampling and analytical processes (see Lai et al. [33] for full details).

#### Statistical analysis

Statistical analyses were performed using IBM® SPSS® Statistics Version 20.0.0 (IBM Corporation, Armonk, NY, USA). Differences in the measured drug residue loads and estimated doses between the two festival years were assessed using Wilcoxon matched-pairs test.

#### Results

##### Prevalence of conventional illicit drugs

The estimated rank order of the daily dose of conventional illicit drugs per 1000 people was cannabis > MDMA > methamphetamine > cocaine (Figure 1). Apart from methamphetamine, estimates were similar across the two festival years. The average daily doses per 1000 people were estimated at 70 for cannabis, 18 for MDMA and 1 for cocaine. Overall, drug consumption steadily increased throughout the festival and peaked on the final day (Figure 1). On the peak day in both years, it is estimated that approximately 100 doses of cannabis, 50 doses of ecstasy and two doses of cocaine were consumed per 1000 people. The average daily consumption of methamphetamine was estimated at about 12 doses per 1000 people in 2010, but significantly decreased ( $P = 0.027$ ;  $Z = -2.2$ ) to only three doses in 2011 (peak doses fell from 23 to 6 per 1000 people, respectively).

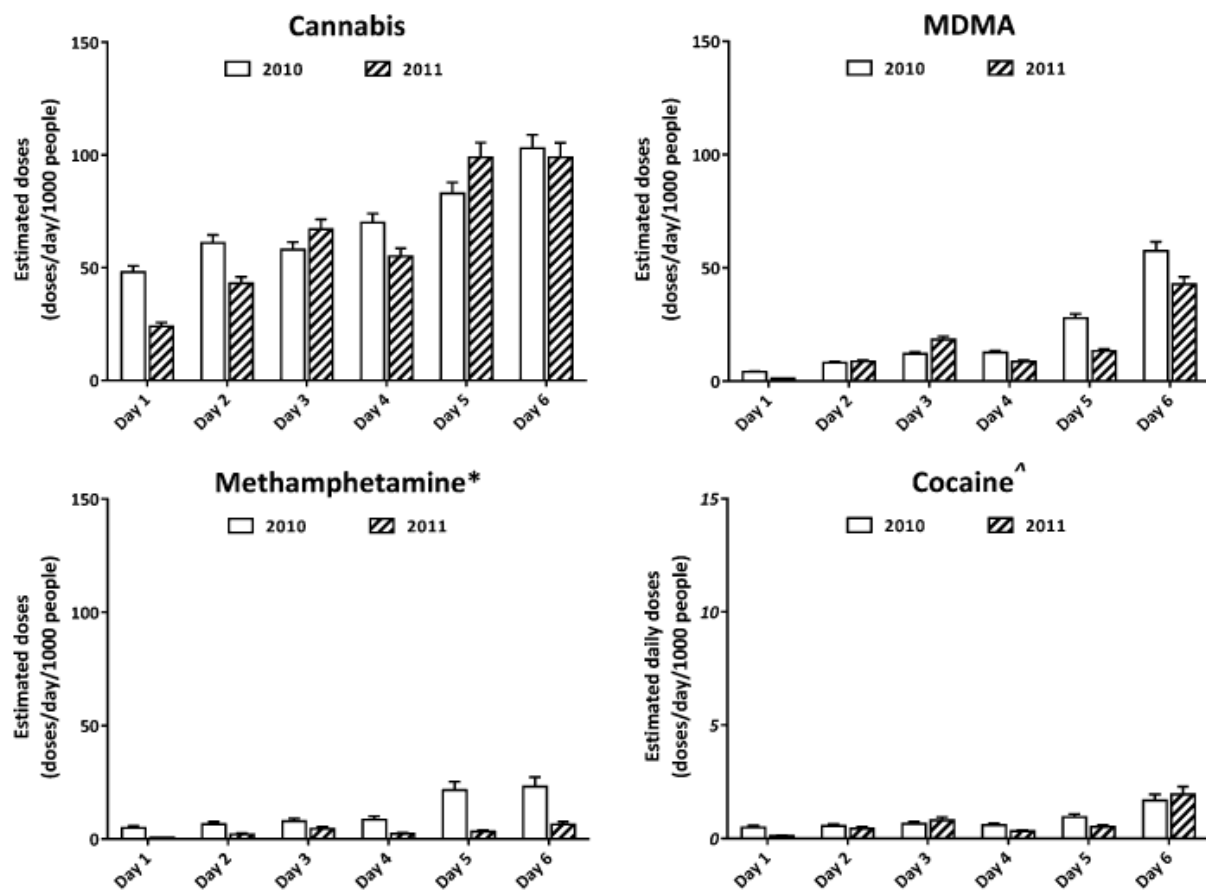


Figure 1. Estimated doses (doses/day/1000 people) of cannabis, MDMA, methamphetamine and cocaine at the festival between 2010 and 2011. The average reference doses: cannabis 20 mg, MDMA 80 mg, methamphetamine 30.5 mg and cocaine 145 mg ([13, 33], Supporting Information Table S3). \* $P < 0.05$ : Wilcoxon matched-pair test comparing data between 2010 and 2011. ^This figure is an order of magnitude lower than all other figures. Error bars consisted of the uncertainty of sampling, chemical analysis, flow measurement, excretion fraction and doses (Supporting Information Table S4) (see Lai et al. [28] for details). MDMA, 3,4-methylenedioxymethamphetamine.

The drug use pattern at the festival (cannabis > MDMA > methamphetamine > cocaine) differed slightly from that identified in a nearby urban area (cannabis > methamphetamine > MDMA > cocaine) over the same period in 2010 [33] (Figure 2). Cannabis consumption (doses/day/1000 people) at the festival was below that in the urban area (50–100 vs. 120–160), as was consumption of cocaine (0.5–2 vs. 1–4). Although the range of methamphetamine consumption at the festival was larger than that in the urban area (5–23 vs. 7–15), the median use at the festival was slightly lower (8 vs. 10). In contrast, MDMA consumption at the festival was substantially higher than in the urban area (4–58 vs. 1–7).



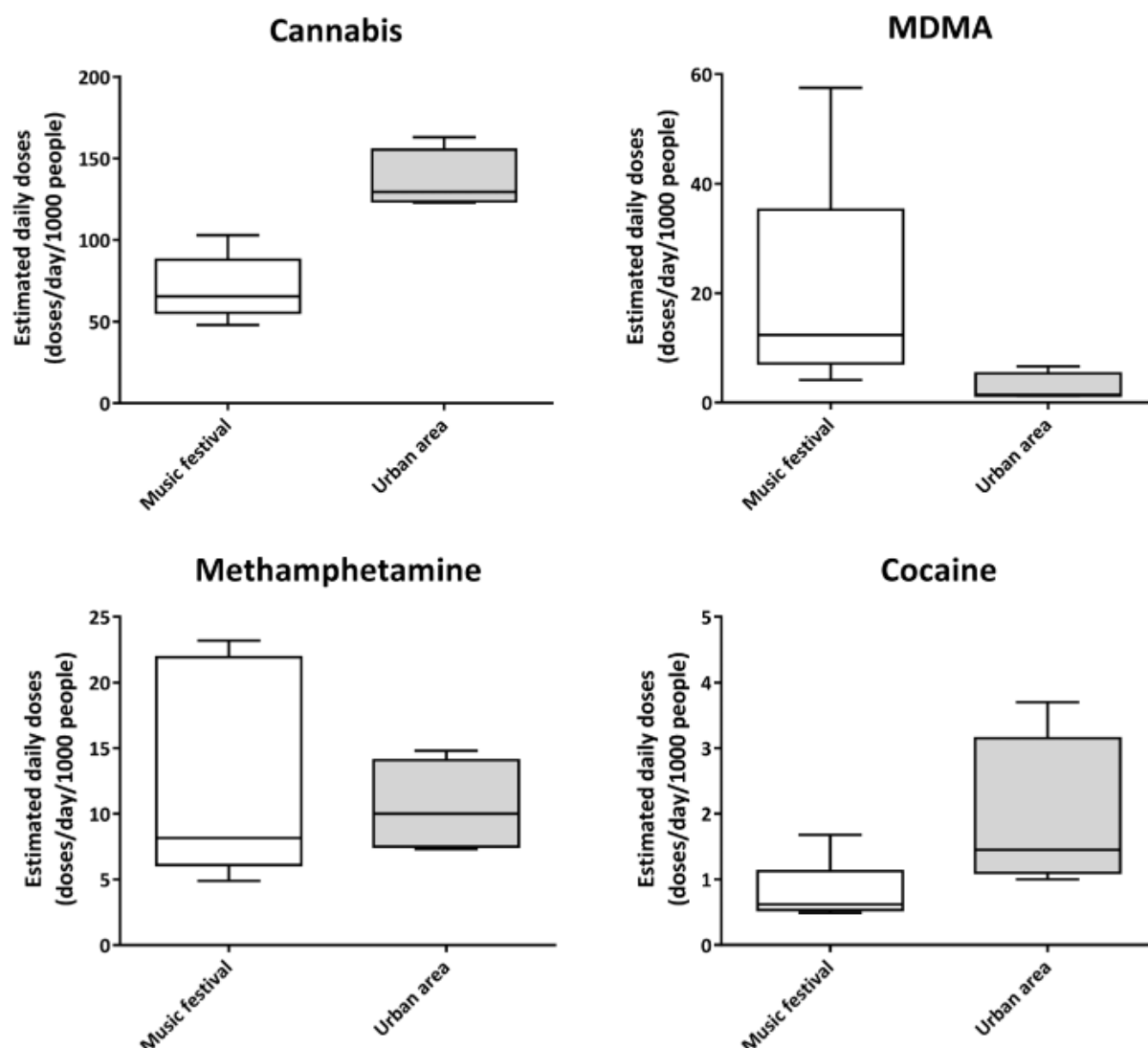


Figure 2. Comparison between the estimated doses (doses/day/1000 people) of the conventional illicit drugs at the festival (white box) and in the nearby urban area (grey box) (see Lai et al. [33] for details) over the same period using wastewater analysis. MDMA, 3,4-methylenedioxymethamphetamine.

#### Loads of emerging illicit psychostimulants

Back estimating consumption of emerging illicit psychostimulants is currently not achievable because human metabolic data are not yet available. However, the mass load of these compounds can be used as an indicator for their use. As with the conventional illicit drugs, daily mass loads (per 1000 people) of these emerging drug residues gradually increased to peak on the last day (Table 2). Benzyl piperazine was detected on five days in 2010 but on only one day (the last day) in 2011 at a significantly lower level ( $P = 0.043$ ;  $Z = -2.0$ ). Similarly, the rate of detection and mass load of mephedrone halved between the two festival years. Methylone was found in all daily samples in 2010 but was detected on only four days in 2011, albeit with a substantially elevated load (16 mg/day/1000 people) on the last day of the 2011 festival.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Average
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Bold and italic: the highest number. \* $P < 0.05$ : Wilcoxon matched-pair test comparing data between 2010 and 2011.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Average (SD)
MDMA, 3,4-methylenedioxymethamphetamine; THC-COOH, 11-nor-9-carboxy-Δ9-tetrahydrocannabinol.							
2010							
Conventional illicit drugs							
MDMA	49	97	150	150	330	690	240 (240)
Methamphetamine	61	77	88	100	250	270	140 (95)
Amphetamine	4.6	10	16	13	37	37	19 (14)
Cocaine	1.3	2.6	3.3	3.1	4.9	5.9	3.5 (1.6)
Benzoylecgonine	28	30	35	31	51	93	45 (25)
THC-COOH	5.8	7.3	7.0	8.4	10	12	18 (16)
Emerging illicit psychostimulants							
Benzyl piperazine	<0.003	6.5	5.5	8.2	16	62	20 (24)
Methylone	2.8	1.6	1.8	1.2	4.4	4.2	2.7 (1.4)
Mephedrone	<0.001	<0.001	1.0	0.7	1.6	1.9	1.3 (0.5)
2011							
Conventional illicit drugs							
MDMA	15	100	220	100	160	510	190 (180)
Methamphetamine	5.1	21	49	25	34	67	34* (22)
Amphetamine	1.8	7.3	11	5.9	9.2	18	8.8 (5.3)
Cocaine	0.3	1.2	3.1	1.8	3.3	12	3.5 (4.1)
Benzoylecgonine	6.2	25	44	17	27	100	37 (35)
THC-COOH	2.9	5.2	8.1	6.6	12	12	7.8 (3.6)
Emerging illicit psychostimulants							

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Average (n.a.)
Benzyl piperazine	<0.003	<0.003	<0.003	<0.003	<0.003	6.7	6.7* (n.a.)
Methylone	<0.001	2.6	2.9	0.6	<0.001	16	5.4 (6.9)
Mephedrone	<0.001	<0.001	0.6	<0.001	<0.001	0.9	0.7 (0.2)

Table 2. Comparison of measured drug residue loads (mg/day/1000 people) in wastewaters between two festival years

## Discussion

To our knowledge, this is the first study using wastewater analysis to estimate daily consumption of conventional illicit drugs and excreted mass loads of emerging illicit psychostimulants at a multiday music festival. This was possible because the relative remoteness of the festival location required its own on-site wastewater treatment plant that only served to the festival. The presence of the target drug residues in the samples collected over two monitoring festival years suggested that consumption of these drugs remained consistent at the festival. While national household survey data that cover the full sampling period are currently unavailable for comparisons, our results partially support self-report data from local consumer surveys in the jurisdiction under study between 2010 and 2011: rates of recent (past 6 month) cocaine use were stable among frequent ecstasy and among injecting drug users [39, 40]; rates of recent cannabis use were stable among injecting drug users [40] but increased significantly among local ecstasy consumers [39]; and the rate of positive MDMA tests in police detainees' urine samples remained stable [41] but use frequency significantly increased among ecstasy consumers [39] and also detection rates of MDMA at Australian borders were higher [42]. The decline in methamphetamine in the wastewater contrasted with consumer survey data over the same period: among police detainees, frequent ecstasy consumers and injecting drug users, increased rates of use were reported [39, 40, 43, 44] as well as increased purity and seizure numbers and weight [42]. The reasons for the significant decline in methamphetamine use in the 2011 festival are uncertain, but probably reflect changes in supply factors specific to this festival. The steady increase in drug use throughout the festival, in the lead in to New Year's Eve, was consistent with findings from our recent study showing holiday effects on rates of drug use over the Christmas and New Year season in the nearby urban area [33]. The overall results of this study complement traditional questionnaire surveys from such events and have the additional advantages that wastewater analysis is more cost-effective and less time-consuming than surveys; the data summarise the population of users rather than individuals; and the results are more objective while avoiding major ethical issues.

Comparing drug use profiles between music festivals and general communities (i.e. an urban area in this case) is useful to recognise the risk of substance use in this kind of event, especially when music festivals are attended by a population at higher risk of using illicit substances and when many of whom are in 'party mode'. Our results suggest that, MDMA aside, levels of drug use at this particular music festival were relatively modest. The organisers confirmed that no drug-related crime and health issues were reported at the festival. This festival is distinguishable from other genres of music festivals, such as 'dance' or 'rock', chiefly because of the wide range of arts in its programme and the breadth of ages among its attendees. The finding on MDMA consumption was consistent with other studies in showing that this drug is favoured by patrons at music events (e.g. [6, 22]). It also indicates

that MDMA use is not limited to the electronica/techno dance scenes because these music genres were not represented at the festival.

In the case of the emerging psychostimulants, benzyl piperazine and mephedrone were illegal at the time of data collection, whereas the legal status of methylone, an analogue of methcathinone, was unclear. It is possible that these substances were sold to consumers under the banner of 'legal highs'. Such substances have been actively marketed at other festivals as ways to escape identification by drug detection dogs [45] and minimise the risk of criminal prosecution [46].

Although the doses consumed of these emerging psychostimulants cannot be estimated, the mass loads measured in the wastewater samples allowed us to monitor changes in use of these substances at the festival across days and years. The substantial reduction in the mass loads of these emerging psychostimulants implies that the market of these emerging drugs at the festival was volatile and possibly decreasing. This is consistent with data reported by frequent ecstasy consumers in this jurisdiction, where reported recent use of mephedrone (16% vs. 14%) and benzyl piperazine (4.5% vs. 2%) declined in the same period (2010 vs. 2011) (methylone was recorded only in the 2011 survey, recently used by 14%) [39]. Thus, use of these emerging drugs may not be widespread in the general Australian community. While to date there are no national population-level estimates for the use of the emerging substances in Australia, the data from wastewater analysis strongly suggest that use of these emerging illicit psychostimulants is relatively low and not yet competitive with conventional illicit substances as mass loads of these emerging illicit psychostimulants were substantially lower than that of the conventional illicit drugs (Table 2).

#### Methodological limitations

Some of the methodological constraints of wastewater analysis [11, 15, 28] need to be considered in interpreting our data. Wastewater analysis cannot deliver information on consumption patterns such as frequency of use (i.e. heavy or light users) or poly-substance use because active amounts of excreted chemicals are collectively measured. This also means that we are unable to infer whether changes in overall use reflect changes in the number of estimated doses, the number of individuals taking the substance, the drug purity or some combination of the three. Interpretation of the estimated prevalence data depends on accurate knowledge of typical doses reported in law enforcement and socio-epidemiological studies. This study may underestimate the usage level because we may miss the samples from those who urinated elsewhere (e.g. bushes) instead of the toilet systems at the festival's campus, but we expect that this is a very small group of people.

#### Conclusion

This study objectively captured the extent of daily illicit substance use at an annual music festival via wastewater analysis. Use of these substances remained consistent at the festival over two consecutive years. Relatively elevated use of MDMA at the festival agreed with findings from previous survey studies, confirming that wastewater monitoring is useful for drug market surveillance systems in parallel to traditional epidemiological methods. Changes in use of methamphetamine and emerging illicit psychostimulants were identified in this study, suggesting that wastewater analysis could be used to measure effectiveness of interventions. The archiving of wastewater samples from music festivals for later analysis could enable authorities to measure the impact of supply and demand reduction policies and initiatives on illicit drug use over time.

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