NEW RESEARCH

When Substance Use Is Underreported: Comparing Self-Reports and Hair Toxicology in an Urban Cohort of Young Adults

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Objective: Large-scale epidemiological research often uses self-reports to determine the prevalence of illicit substance use. Self-reports may suffer from inaccurate reporting but can be verified with objective measures. This study examined the following: the prevalence of illicit and non-medical substance use with self-reports and hair toxicology, the convergence of self-reported and objectively quantified substance use, and the correlates of under- and overreporting.

Method: The data came from a large urban cohort study of young adults (n = 1,002, mean age = 20.6 years, 50% female). The participants provided 3 cm of hair (covering the previous 3 months) and reported their illicit and non-medical substance use and their sociodemographic, psychological, and behavioral characteristics. Hair toxicology analyses targeted cannabinoids, ketamine, opiates/opioids, stimulants including 3,4-methylenedioxymethamphetamine, and relevant metabolites.

Results: Self-reports underestimated the prevalence of most substances by 30% to 60% compared to hair tests. The average detection ratio (hair test/self-report) was 1.50. Hair tests were typically more sensitive than self-reports. Underreporting was associated with a low level of that substance in hair. Self-reported delinquency and psychopathology were correlated with an increased likelihood of concordant positive self-reports and hair tests compared to underreporting. Overreporting was associated with infrequent self-reported use.

Conclusion: Our study suggests that self-reports underestimate young adults' exposure to illicit substances and non-medical use of prescription drugs. Consequently, estimates of associations between substance use and risk factors or outcomes are likely biased. Combining self-reports with hair tests may be most beneficial in study samples with occasional substance use. Researchers can use specific factors (eg, detection ratios) to adjust prevalence estimates and correlations based on self-reports.

Key words: substance use; non-medical use of prescription drugs; hair toxicology; prevalence; young adults

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Illicit substance use (eg, cannabinoids, stimulants, opiates) and non-medical use of prescription drugs (eg, opioids, ketamine) are widespread public health problems.[1,2] Estimates of substance use prevalence from large-scale epidemiological studies are primarily based on self-reported data.[3-7] Self-report surveys have many strengths, including the possibility of assessing the time and mode (eg, frequency, context, motivation) of substance use, the relatively low threshold for participating, and the comparatively low costs for researchers. However, self-reports may suffer from underreporting[8,9] and could be verified with objective measures to assess the prevalence of substance use more reliably. Such evidence is especially crucial for young adults, who are at the peak age of substance use.[3]

Toxicological hair testing is a non-invasive technique that precisely quantifies a person's average exposure to specific substances during the past months,[10-14] with few exceptions (eg, the reliability of hair tests is poor for sporadic or mild exposure to cannabis[15]). However, compared to self-reports, the feasibility of hair testing can be limited, for example because of the unwillingness or inability of some participants to provide (enough) hair for testing, as well as the costs associated with toxicological analyses. These obstacles may explain why previous comparisons of hair toxicology and self-reported data have been primarily based on relatively small and mostly clinical or high-risk samples,[16-21] with the exception of a few larger-scale studies on mid-adult males,[22] late adolescents,[23] or age-heterogeneous samples.[24] Indeed, insights into the concordance of self-reported substance use and hair tests in young adults from the community remain limited.

Using statistics, such as agreement, Cohen's kappa, sensitivity, and specificity (definitions in Table 1),[10,25] the previous evidence suggests that concordance between self-reported and hair data ranges from poor to moderate, whereas prevalence estimates of substance use were typically higher when using hair tests instead of self-reports.[10] However, several of the previous studies focused on legal[26] or small sets of illicit[24,27] substances, whereas comparisons for larger sets of illicit substances within 1 study, and especially for non-medical use of prescription drugs, are currently lacking.

Correlates of Discordance Between Self-Reports and Hair Tests

Individual correlates of underreporting one's substance use (ie, reporting that one *has not* used a substance although one has) or overreporting it (ie, reporting that one *has* used a substance although one has not) may be used to adjust self-reported data and more accurately reflect substance use in future work. Under- and overreporting could be due to misremembering the time frame of substance use (ie, recall bias)[28] or a lack of knowledge about the substances used (eg, being exposed to contaminated substances or intending to buy one substance [eg, cocaine] but getting another [eg, amphetamine] instead).

TABLE 1 Definitions of Key Statistics Used in the Comparison of Hair Tests and Self-Reports

Statistic	Definition
Detection ratio	Prevalence hair tests/ prevalence self-reports
Agreement	Percentage of participants with concordant self-reports and hair tests
Kappa	Chance-corrected agreement, as proposed by Cohen
Hair test specificity	Proportion of participants with negative hair tests in the group of those with negative self-reports
Hair test sensitivity	Proportion of participants with positive hair tests in the group of those with positive self-reports
Self-report specificity	Proportion of participants with negative self-reports in the group of those with negative hair tests
Self-report sensitivity	Proportion of participants with positive self-reports in the group of those with positive hair tests

Alternatively, discordance between self-reports and hair tests could reflect differences in the possible implications of self-reports vs hair tests. For example, for those with only low concentrations of substances or metabolites in hair, toxicological analysis may not be able to distinguish accidental environmental exposure from intentional use.[29] This could result in positive hair tests that are rightly not confirmed by self-reports on substance *use*.

Finally, response patterns, such as social desirability bias[30] and unwillingness to disclose substance use can play a role. Some previous studies have found that participants from racial or ethnic minority backgrounds[22,24] and those with low antisocial behavior levels[22,23] tended to underreport their illicit substance use, perhaps because they feared the legal or social consequences of illicit substance use more than their peers. Conversely, we assumed that participants with low self-control (or, reversely, high impulsivity, which could also be indicated by attention-deficit/hyperactivity disorder [ADHD] symptoms) might be relatively more likely to self-report substance use, because they may not consider the potential consequences of doing so.[31] In addition, those who report socially undesirable behaviors in other domains (eg, delinquency) may be more likely to also self-report substance use.

Our study combines state-of-the-art hair toxicology analysis with self-reports over the previous 3 months in a large community sample of urban young adults. Our goals were: (1) to estimate the prevalence of young adults' illicit substance use and non-medical use of prescription drugs with objective data; (2) to assess the convergence of self-reported and objectively quantified substance use; and (3) to identify the correlates of discordance between self-reports and hair tests. Specifically, we investigated indicators of the following: difficulties in remembering the timing of substance use (eg, due to occasional use); environmental contamination; and an overall inclination or hesitancy to report socially undesirable behaviors (eg, delinquency, aggression) and psychopathology (eg, low self-control, ADHD, internalizing symptoms).

METHOD

Recruitment and Participants

This study used data from the Zurich Project on the Social Development from Childhood to Adulthood (z-proso). In 2004, a total of 1,675 children from 56 primary schools were selected using a cluster-stratified randomized sampling

TABLE 2 Sample Characteristics and Descriptive Statistics of the Main Study Variables

Variable	n	Items[a]	α[b]	% (n)	Mean	SD
Socio-demographics						
Age	1,002				20.57	0.38
Sex	1,002					
Female				50.2 (503)		
Male				49.8 (499)		
Parental socio-economic status (ISEI)	956				47.06	19.8
Parental educational degree (highest in household)	804					
University degree				30.6 (246)		
Other				69.4 (558)		
Participant highest educational degree	1,002					
Compulsory and preparatory vocational				24.0 (240)		
Vocational				49.3 (494)		
Academic				26.7 (268)		
Participants' place of birth	804					
Participants born in Switzerland				90.4 (727)		
Participants born abroad				9.6 (77)		
Parental migration background	984					
Both parents born in Switzerland				25.0 (246)		
One parent born abroad				27.6 (272)		
Both parents born abroad				47.4 (466)		
Parental place of birth[c]	981					
Switzerland				52.7 (517)		
European Union and other European countries				27.8 (272)		
Asia (including Turkey)				20.3 (199)		
Former Yugoslavia				16.1 (158)		
Latin America				6.9 (68)		
Sub-Saharan Africa				4.3 (42)		
Northern Africa				2.4 (24)		
USA, Canada, New Zealand, Australia				2.1 (21)		
Psychological and behavioral correlates						
Physical aggression	1,002	3	0.86		1.20	0.46
ADHD symptoms	1,002	4	0.79		2.72	0.76
Internalizing symptoms	1,002	15	0.92		2.19	0.75
Delinquency	1,001	24			2.56	2.25
Low self-control	1,002	10	0.74		2.07	0.42
Hair sample characteristics						
Hair type	1,002					
Scalp				91.1 (913)		
Other (arm, leg, chest)				8.9 (89)		
Weight of hair assessed (mg)	1,002				12.76	4.74
Hair treatment	1,002					
Participants with hair bleaching				19.6 (196)		

(continued)

TABLE 2 Continued

Variable	n	Items[a]	α[b]	% (n)	Mean	SD
Participants without hair bleaching				80.4 (806)		
Hair color	1,001					
Light				23.6 (236)		
Brown				54.0 (541)		
Dark				22.4 (224)		

Note: ADHD = attention-deficit/hyperactivity disorder; ISEI = International Socio-Economic Index of Occupational Status.
[a]Number of items used to compute multi-item scales.
[b]Cronbach's alpha for multi-item scales based on study sample.
[c]Numbers add up to more than 100% because information on both parents is included.

approach.[32] Regular follow-up assessments were carried out until 2018, when the participants were 20 years old (n = 1,180). At that time, computer-administered self-interviews (CASI) were conducted with most participants in a university laboratory environment (38 participants were interviewed via telephone). The 1,142 participants who came to the laboratory were subsequently invited to donate 3 cm of proximal hair, which allows for the detection of psychoactive substances stored in their hair from approximately the past 3 months. If the scalp hair was shorter than 1 cm, the participants provided arm, leg, or chest hair. In total, 1,016 participants agreed (89% of the sample), and hair samples were collected from 1,003 participants. Because of a data collection error, the hair sample of 1 participant could not be matched with the survey data, resulting in a final sample size of 1,002. Those participating in the hair study completed an additional questionnaire to assess important covariates (eg, hair color).

Consistent with Switzerland's immigration policies and Zurich's diverse population, the participants' parents were born in more than 80 different countries, including in Europe, Asia, Africa, America, and other regions (Table 2). Parents had diverse backgrounds in terms of educational degrees and the household socioeconomic status, measured as International Socio-Economic Index of Occupational Status (ISEI; scores range from 16 [eg, unskilled worker] to 90 [eg, judge]).[33] At age 20 years, almost half of the participants had a vocational degree, and the others had either an educational degree that permitted university entrance or no other degree beyond compulsory schooling. No significant group differences emerged between those who donated hair vs those who did not in terms of sex, parental migration or socioeconomic background, educational degree, or self-reported 3-month substance use.

This study was consistent with national and international ethics standards and approved by the responsible ethics committees (Cantonal Ethics Committee Zurich [BASEC #2017-02021] and the Ethics Committee of the Faculty of Arts and Social Sciences, University of Zurich). The participants provided their written informed consent. They received a cash incentive (∼US $105 altogether [ie, for main survey and donating hair]).

Measures

Self-Reported Substance Use. The participants were presented with a list of substances, including cannabinoids, stimulants, hallucinogens, medical and non-medical opiates, and medical opioid painkillers (Table S1, available online, provides a full list of substances assessed). They indicated how often they had used each substance in the previous 3 months (0 = never, 1 = once, 2 = 2-5 times, 3 = weekly, 4 = [almost] daily) and 12 months (1 = never, 2 = once, 3 = 2-5 times, 4 = 6-12 times [monthly], 5 = 13-52 times [weekly], 6 = 53-365 times [daily]). For medications, participants were asked to indicate non-medical use only, including higher dosage or more frequent use than prescribed. On the additional hair study questionnaire, participants indicated their use of prescribed and over-the-counter medications.

We created dummy variables to represent the use of or abstinence from a particular substance during the previous 3 or 12 months, respectively. For self-reported cannabis use, we created 2 dummy-coded variables—one indicating weekly or daily use vs less/no use and another indicating daily use vs less/no use—because hair toxicology analyses can typically detect only regular or intense exposure to cannabis.[15] Because of a programming error, the 3-month self-reports for 3,4-methylenedioxymethamphetamine (MDMA) were not assessed. We estimated the "by proxy" prevalence of MDMA using the self-report ratio for other stimulants (ie, cocaine and amphetamine, which are both often used in similar contexts [eg, night-life]) from 3 to 12 months as follows:

Hair Toxicological Analyses. We quantified the substances and their metabolites with liquid chromatography−tandem

$$3\ month\ prevalence\ MDMA\ = 12 month\ prevalence\ MDMA * \left(\left(\left(\frac{3\ month\ prevalence\ cocaine}{12\ month\ prevalence\ cocaine} \right) + \left(\frac{3\ month\ prevalence\ amphetamine}{12\ month\ prevalence\ amphetamine} \right) \right) \Big/ 2 \right).$$

mass spectrometry, which is described elsewhere based on different data.[34,35] Supplement 1, available online, provides a brief summary of the procedure, and Table S2, available online, provides a list of all substances and metabolites used in this paper. To assess any exposure to a particular substance (including 1-time and random use), we created dummy variables indicating whether the concentration of a particular substance or metabolite was above the lower limit of quantification (LLOQ; coded 1) or not (coded 0, meaning that no exposure was detected). For a supplementary analysis, we also considered the concentrations of particular substances or metabolites in the form of continuous variables.

To assess the non-medical use of codeine and opioid painkillers, we recoded respective positive hair tests as 0 if the participant had reported medical use of codeine or opiate/opioid painkillers during the past 3 months (hair study questionnaire). This was not done when the participant additionally reported unprescribed doses of the substance in the survey questionnaire. In addition, we conducted sensitivity analyses that excluded participants who reported the prescribed use of the respective medical drugs.

Coding of Under- and Overreporting. For simplicity, we use the terms under- and overreporting to indicate discordance of self-reports and hair tests. We created 2 binary variables. We coded underreporting as 1 if a participant reported not having used a substance but their hair test showed a positive result, and as 0 if the self-report and hair test were both positive. We coded overreporting as 1 if a participant reported substance use that was not detected in their hair, and as 0 if the self-report and hair test were both negative.

Psychological and Behavioral Correlates of Underreporting, Self-Reported at Age 20 Years. We assessed delinquency in the previous year with a 24-item binary checklist, including minor delinquent and deviant acts (eg, producing illegal graffiti) and major delinquent acts (eg, assault). We computed a sum score. Furthermore, we used subscales from the Social Behavior Questionnaire[36] to assess physical aggression (eg, physically attacked someone), symptoms of ADHD as a proxy for impulsivity (eg, done things without thinking), and internalizing symptoms (eg, being sad without a reason). Participants indicated how often they had engaged in these behaviors or how often these feelings had occurred on a 5-point scale from 1 = never to 5 = very often. The reference period was the previous year for physical aggression and ADHD and the previous month for internalizing symptoms. Finally, we assessed low self-control with items from the Self-Control Scale (eg, I often act on the spur of the moment without stopping to think).[37] Responses ranged from 1 = fully untrue to 4 = fully true. For each scale, we averaged the items.

Sociodemographic Characteristics. We measured sex (0 = female, 1 = male), parental migration background (0 = at least 1 parent born in Switzerland, 1 = both parents born abroad), household socioeconomic background (ISEI) during adolescence, and the participant's highest educational degree achieved by age 20 years (dummy variables indicating the following: compulsory schooling and preparatory vocational education; academic education; and vocational degrees, with the latter being used as the reference category in regression models).

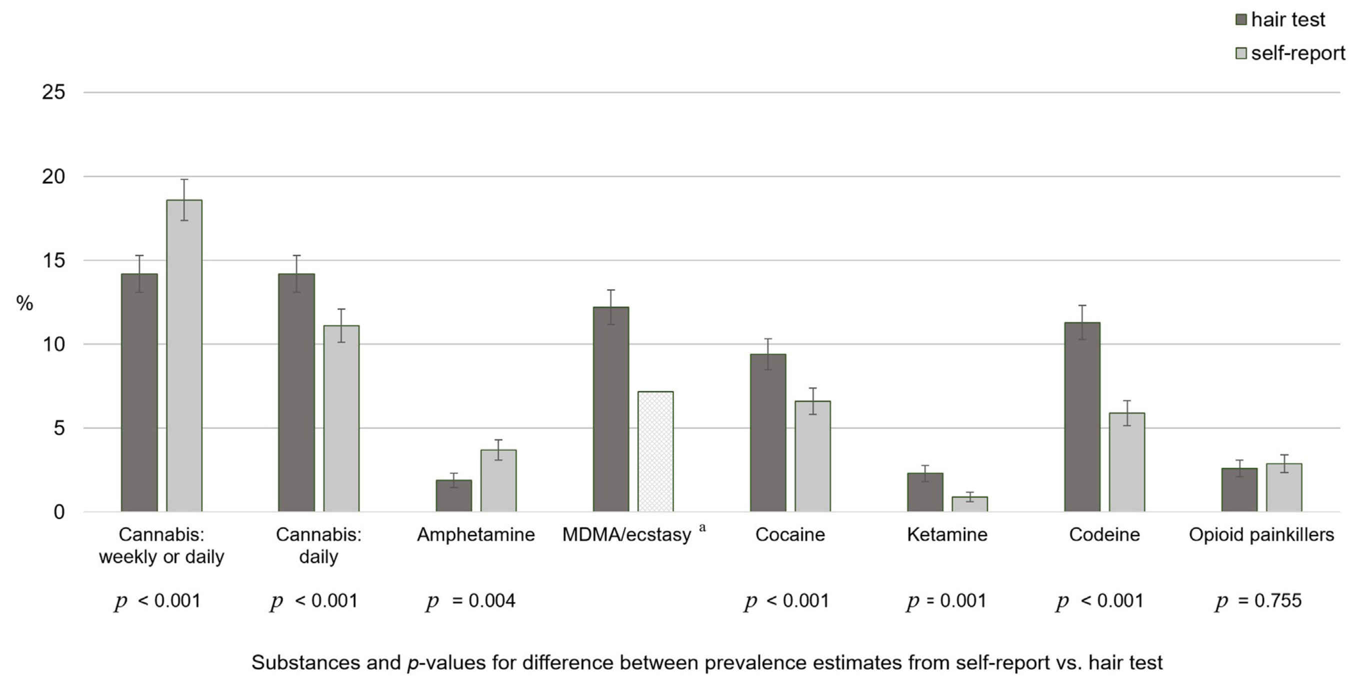
Control Variables. Dummy variables indicating any hair bleaching (0 = no, 1 = yes) and hair color (light and dark vs brown) were included because these factors can influence the results of hair toxicology analyses.[38-40]

Analytical Strategy

We compared prevalence estimates from self-reports and hair toxicology analyses using the McNemar test. We calculated the hair test detection ratio, test agreement, specificity, and sensitivity[10,25] based on (1) the full sample and (2) an optimal sample of participants who provided scalp hair of ≥3 cm that weighed ≥5 mg (n = 830). Female participants were overrepresented slightly in the optimal sample (56%).

To examine the role of recall bias in underreporting, we used positive 12-month self-reports to identify participants who were generally willing to disclose their substance use. To examine the role of recall bias in overreporting, we used χ^2 tests to investigate whether the number of participants with occasional use (ie, 1-time use during the previous 3 months) was higher among participants with overreporting compared to those with concordant positive self-reports and hair tests.

FIGURE 1 Prevalence of Substance Use According to the Hair Analyses and Self-Reports for the Previous Three Months (Full Sample)



Note: The p values were obtained from the McNemar test.
[a]*For 3,4-methylenedioxymethamphetamine (MDMA)/ecstasy, 3-month self-reports were not available, and the self-report prevalence was estimated (see Method section for details).*

To assess the role of the residue of substances used more than 3 months ago or accidental environmental exposure, we examined whether participants with underreporting had lower concentrations of the substances and metabolites in their hair than those with concordant positive self-reports and hair tests. We used the non-parametric Mann−Whitney test. For cocaine, we also conducted an analysis of metabolic ratios (ie, benzoylecgonine/cocaine and norcocaine/cocaine) to determine environmental contamination.[29]

Finally, to examine the role of response biases in underreporting, we tested behavioral and psychological predictors of underreporting in binary logistic regressions. These analyses were conducted for cocaine and codeine to include 1 illicit substance and 1 medical substance with considerable baseline prevalence. The models adjusted for the concentration of the respective substances and their metabolites in hair to account for accidental substance exposure or exposure that had occurred more than 3 months ago.

RESULTS

Prevalence

Illicit Substances. Cannabis was the illicit substance most frequently detected in hair, followed by MDMA, cocaine, ketamine, and amphetamine (Figure 1, Table 3[41]). More than 1 in 6 participants (17%) tested positive for at least 1 illicit substance other than cannabis in hair. The prevalence of heroin use was zero, and fewer than 5 participants had used 2C psychedelics according to both self-reports and hair tests. Therefore, these substances were excluded from the concordance analyses.

The prevalence estimates based on hair tests were significantly higher than those based on self-reports for all illicit substances, except amphetamines. Self-reports underestimated the prevalence of young adults' exposure to illicit substances by about 30% to 60% compared to the hair data. The prevalence of cannabis detectable in hair was higher than the self-reported prevalence of "weekly or daily" use and less than that of self-reported "daily" use. Excluding cannabis, the average detection ratio (hair tests/self-reports) was 1.55 based on the full sample and 1.66 based on the optimal sample.

Non-medical Use of Prescription Drugs. The hair tests indicated that 13% of the participants had used an opiate or opioid non-medically, with codeine being the most prevalent. The participants significantly underreported their non-medical codeine use. A sensitivity analysis excluding

TABLE 3 Comparison of Self-Reports and Hair Toxicology Analyses: Substance Use During the Previous Three Months

		Prevalence comparison			Test comparison					
Substances	**Sample size[a]**	**Positive hair test % (n)**	**Positive self-report % (n)**	**Detection ratio**	**Agreement**	**Kappa[b]**	**Hair test specificity**	**Hair test sensitivity**	**Self-report specificity**	**Self-report sensitivity**
Full sample										
Cannabis weekly or daily[c]	1001	14.2 (142)	18.6 (186)	0.76	90.4	0.651	96.8	62.4	91.9	81.7
Cannabis daily[c]	1001	14.2 (142)	11.1 (111)	1.28	91.7	0.625	93.6	76.6	97.0	59.9
Amphetamines	1002	1.9 (19)	3.7 (37)	0.51	96.6	0.377	99.2	29.7	97.4	57.9
MDMA/ecstasy[d]	1002	12.2 (122)	*7.19*[d]	*1.70*[d]	—	—	—	—	—	—
Cocaine	1001	9.4 (94)	6.6 (66)	1.42	93.6	0.566	95.1	72.7	98.0	51.1
Ketamine	1002	2.3 (23)	0.9 (9)	2.56	98.2	0.430	98.4	77.8	99.8	30.4
Codeine[e]	1002	11.3 (113)	5.9 (59)	1.92	88.6	0.282	91.1	49.2	96.6	25.7
Opioid painkillers[e]	1001	2.6 (26)	2.9 (29)	0.90	95.9	0.234	98.0	24.1	97.7	26.9
Optimal hair sample[f]										
Cannabis weekly[c]	829	13.6 (113)	18.0 (149)	0.76	90.8	0.657	97.1	62.4	92.2	82.3
Cannabis daily[c]	829	13.6 (113)	10.4 (86)	1.31	92.4	0.641	93.9	79.1	97.5	60.2
Amphetamines	830	1.9 (16)	3.4 (28)	0.56	96.9	0.394	99.1	32.1	97.7	56.3
MDMA/ecstasy[d]	830	10.2 (85)	*6.90*[d]	*1.48*[d]	—	—	—	—	—	—
Cocaine	829	7.6 (63)	5.8 (48)	1.31	94.8	0.585	96.3	70.8	98.2	54.0
Ketamine	830	2.3 (19)	0.7 (6)	3.29	98.2	0.393	98.3	83.3	99.9	26.3
Codeine[e]	830	10.6 (88)	5.3 (44)	2.00	89.4	0.283	91.6	50.0	97.0	25.0
Opioid painkillers[e]	829	2.3 (19)	2.8 (23)	0.82	95.9	0.170	98.1	17.4	97.7	21.1

Note: *MDMA = 3,4-methylenedioxymethamphetamine.*

[a]*Includes cases with valid data from both hair samples and self-reports.*

[b]*Interpretation: <0.00 = poor; 0.00-0.20 = slight; 0.21-0.40 = fair; 0.41-0.60 = moderate; 0.61-0.80 = substantial; 0.81-1.00 = almost perfect.*[41]

[c]*Hair toxicology analysis can typically detect only regular or intense exposure to cannabis.*[15] *Because hair tests reveal the concentration, not the frequency of use, the most adequate corresponding time frame for self-reports remains unknown. Therefore, we provide comparisons of hair tests with frequent self-reported cannabis use using the categories of "weekly to daily use" vs "less/no use" and of "daily use" vs "less/no use."*

[d]*For MDMA/ecstasy, 3-month self-reports were not available, and we estimated the self-report prevalence (see Methods for details); data based on estimated prevalence are given in italics.*

[e]*Corrected for self-reported medical use.*

[f]*Refined sample with hair from scalp, weighed portion ≥5 mg and hair length ≥3 cm.*

participants with self-reported medical use of prescription drugs yielded similar results (Table S3, available online). The average detection ratio (hair tests/self-reports) was 1.41 based on both the full and optimal samples.

Across substances, the prevalence was slightly lower in the optimal sample than in the full sample, possibly due to the slight overrepresentation of female participants in the optimal subset (ie, female participants had a lower prevalence of substance use than male participants; Supplement 2 and Figure S1, available online). Under- and overreporting trends did not differ between the full and optimal samples, indicating that hair toxicology analysis performs reasonably well, even when up to 17% of the hair samples are of suboptimal quality.

Test Comparisons

Agreement between hair tests and self-reports was close to or above 90% for all substances (Table 3). Agreement was higher among substances with lower base rates. The Cohen kappa indicated that test concordance ranged from fair (medical drugs and amphetamines) to moderate (cocaine and ketamine) to substantial (cannabis). The hair tests had better sensitivity than the self-reports in most cases, indicating that the hair tests more often replicated positive self-reports than vice versa. For codeine and ketamine, the hair tests were almost or even more than twice as sensitive as self-reports. In turn, the specificity of the hair tests was typically lower than that of the self-reports, meaning that the hair tests did not confirm negative self-reports as often as negative self-reports confirmed negative hair tests. All figures indicating agreement, concordance, sensitivity, and specificity changed minimally when using the optimal sample.

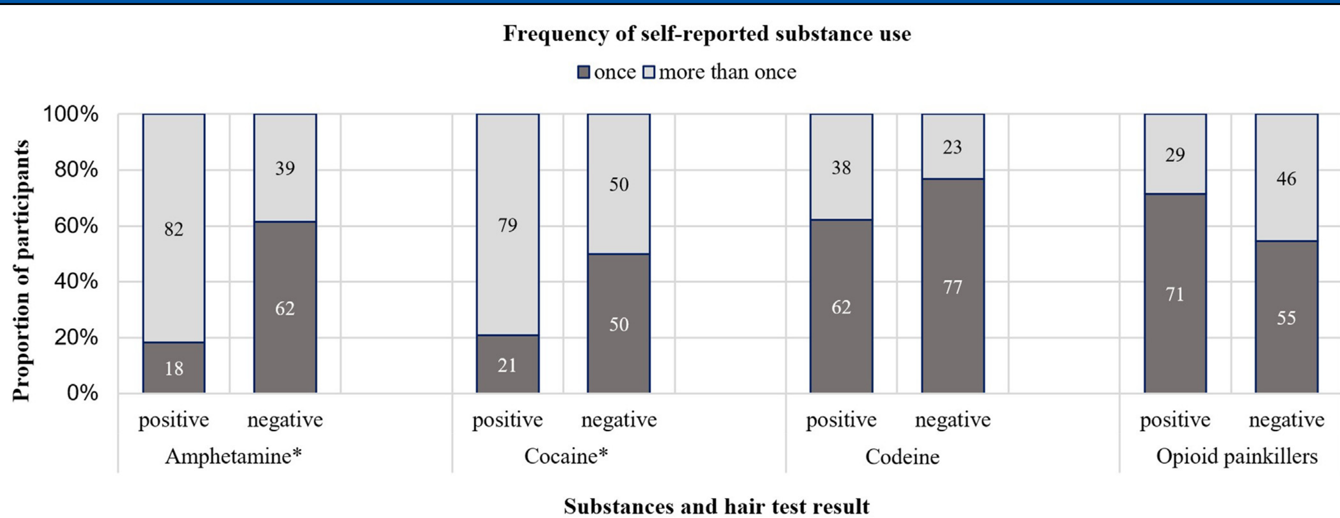
Correlates of Discordance

Underreporting was more prevalent than overreporting (full sample: 15% [n = 146] vs 8% [n = 81]; optimal sample: 14% [n = 112] vs 8% [n = 64]). Polysubstance use is common in our sample,[42] and we found that individual participants under- or overreported up to 3 substances.

Indication of Recall Bias. All participants who had a negative self-report for amphetamine or opioid painkillers use during the previous 3 months despite a positive hair test had also not reported use of the respective substance during the previous 12 months. In contrast, 19% or more of those with a negative 3-month self-report for cocaine, ketamine, or codeine despite a respective positive hair test, and 77% of those with a negative self-report for cannabis despite a positive hair test, had a respective positive 12-month self-report (Table S4, available online).

Participants with a positive self-report and a negative hair test for amphetamine or cocaine were significantly more likely to report 1-time use (indicating occasional use) than those with concordant positive self-reports and hair tests (Figure 2). We detected no such pattern for medical drugs.

FIGURE 2 Who Overreports Substance Use? Self-Reported Frequency of Substance Use During the Previous Three Months by Hair Test Result in the Groups of Participants With a Positive Self-Report for the Respective Substance



Note: Cannabis was excluded from this analysis because the self-report baseline was set to "weekly or daily" use in our main analyses. Ketamine was excluded because of a low number of positive self-reports combined with a negative hair test (n < 5). In some bars, numbers add up to more than 100% because of rounding. *p < .05 (difference between groups with positive vs negative hair test).

TABLE 4 Who Underreports Substance Use? Odds Ratios (95% CIs), *p* Values for Associations Between Predictors and Underreporting

	Cocaine n = 94 (including 46 with negative self-report)		Codeine n = 113 (including 84 with negative self-report)	
Predictors	Separate models[a]	Full model[b]	Separate models[a]	Full model[b]
Sex: male	1.28 (0.41-3.98), 0.667	—	0.69 (0.26-1.85), 0.462	—
Parental socioeconomic status	0.99 (0.96-1.01), 0.316	—	0.99 (0.96-1.01), 0.280	—
Participant educational degree: Compulsory (reference: vocational)	1.32 (0.49-3.56), 0.579	—	0.48 (0.18-1.32), 0.155	—
Academic (reference: vocational)	0.41 (0.08-2.03), 0.273	—	0.35 (0.09-1.38), 0.132	—
Parental migration background	2.64 (0.93-7.53), 0.069	—	1.11 (0.38-3.31), 0.846	—
Delinquency	0.78 (0.65-0.93), 0.005	0.78 (0.65-0.94), 0.007	0.77 (0.65-0.92), 0.003	—
Physical aggression	0.71 (0.35-1.47), 0.360	—	0.89 (0.40-1.99), 0.768	—
Low self-control	0.35 (0.11-1.14), 0.082	—	0.17 (0.06-0.53), 0.002	0.22 (0.07-0.71), 0.012
ADHD symptoms	0.44 (0.23-0.86), 0.017	0.43 (0.21-0.89), 0.022	0.51 (0.29-0.88), 0.015	—
Internalizing symptoms	0.82 (0.45-1.51), 0.529	—	0.39 (0.22-0.68), <0.001	0.43 (0.24-0.77), 0.005

Note: ADHD = attention-deficit/hyperactivity disorder.
[a]*For each predictor, a separate model was tested, adjusting for hair color, bleaching, and the concentration of substance and metabolites in hair (ie, belonging to the upper 25% of the distribution vs lower concentrations).*
[b]*All predictor variables with p values <.10 from separate models were entered simultaneously in the first step, and in the second step, predictors with unique effects at p values >.10 were excluded from the full model.*

Residue of Substances Used More Than 3 Months Ago and Accidental Exposure. Participants with negative self-reports despite positive hair tests for amphetamine, cocaine, ketamine, and codeine had lower concentrations of these substances in hair than those with concordant positive self-reports and hair tests (Figure S2, available online). The metabolic ratios for cocaine indicated that less than 1 in 10 cases of underreporting were likely due to environmental contamination (Table S5, available online).

Behavioral and Psychological Correlates of Underreporting. The regression analyses indicate that sociodemographics were not associated with underreporting cocaine and codeine use. Delinquency and ADHD symptoms were associated with a decreased risk of underreporting (Table 4); these associations remained significant in the full model for cocaine. Higher levels of internalizing symptoms and lower self-control were associated with a lower risk of underreporting codeine use. A sensitivity analysis excluding participants with self-reported medical codeine use yielded similar results, with the exception that participants with an educational degree that qualified them for university entrance had a lower risk of underreporting their codeine use than those with a vocational degree (Table S6, available online).

DISCUSSION

This study combines self-report survey instruments and hair toxicology methods to assess illicit substance use and non-medical use of prescription drugs in a large-scale community study of urban young adults. Table 5 summarizes implications of our findings for future research, which are discussed below.

Prevalence

Our results show that the self-reported data underestimated the prevalence of young adults' exposure to illicit substances and the non-medical use of prescription drugs. Previous research had focused primarily on small subsets of the substances considered here (eg, cannabis, cocaine) while neglecting others (eg, ketamine and codeine).[10] A recent review suggested that self-reports of frequent cannabis use are more accurate than self-reports of other illicit substance use, perhaps because cannabis use is more socially accepted.[10] Our findings are consistent with this notion. Going forward, researchers assessing self-reported substance use may choose to apply detection ratios from studies like ours to correct prevalence estimates of substance use in their samples or to create measures of uncertainty to account for the possibility of higher rates. For example, our data indicate that in populations comparable to our sample, the prevalence of cocaine

TABLE 5 Recommendations for Researchers Studying the Use of Illicit Substances and Non-medical Use of Prescription Drugs: Opportunities for Combining Self-Reports With Information From Hair Analyses

Planning data collection	Estimating prevalence	Examining correlates
➢ If possible, combine self-report with hair toxicology data. If resources are limited, choose subgroups for hair analyses that are prone to incorrect self-reporting (eg, respondents with occasional substance use). ➢ Prior to collecting hair data, assess the risk of nonresponse (here: 11%, in a city with liberal attitudes toward substance use). ➢ Consider whether hair toxicology analysis is suitable for the substances of interest (eg, not suitable for identifying occasional cannabis use). ➢ If collecting hair samples, find a reputable laboratory/collaborator with expertise in hair analysis and the capacity to process the expected number of hair samples. Get a quote for expected costs. Factor in additional time and personnel for hair sample collection. ➢ If assessing self-reports only, use short recall periods (eg, 3 months) combined with long periods (eg, 12 months). Also use graded response categories for assessing the frequency of substance use.	➢ Adjust prevalence estimates derived from self-reports for illicit substance use and non-medical use of prescription drugs. Base these adjustments on average rates of incorrect reporting in comparable samples that assessed both self-report and hair data. (In a population like ours, respondents underreport illicit substance use and non-medical use of prescription drugs by 50% on average.) ➢ Correct prevalence rates derived from self-reports for substances based on their specific detection ratios, keeping in mind that the reliability of self-reports varies by substance (eg, depending on the social acceptability of its use). ➢ Consider that the reliability of hair tests is limited for some substances (eg, cannabis, amphetamine). For these substances, estimate only the prevalence of use patterns that can be detected reliably (eg, frequent cannabis use) or apply average detection ratios based on similar substances (eg, substances that are typically used in similar contexts or for similar purposes) to adjust estimates.	➢ When using self-reports only, adjust for self-reported psychopathology and behaviors (eg, internalizing symptoms, delinquency). This practice adjusts estimates for social desirability and other relevant response patterns. ➢ If hair data is available, create combined substance exposure variables based on both self-reports and hair data that most accurately reflect actual substance use.

exposure is likely 1.4 times the self-reported prevalence; for ketamine, this factor is 2.6.

The prevalence estimates from our hair toxicology analyses considerably exceeded those from national and European self-report surveys.[43,44] It is concerning that in the previous 3 months, 9% of young adults had been exposed to cocaine, and 13% had used non-heroin opiates or opioids (mainly codeine but also opioid pain killers), likely without a medical need, especially as these substance classes have a high potential for addiction.[45] In a previous investigation of self-reported lifetime and past-year substance use in the current sample,[46] reasons for the high prevalence of substance use in Zurich were discussed, including the urban high-resource setting (eg, high availability of substances combined with a high-income population) and cultural features (eg, cannabis use is socially widely accepted in Zurich despite still being illegal).[47]

Test Comparisons

Test concordance was relatively high in our study compared to that in previous research, at least for the illicit substances.[10] Nevertheless, the hair toxicology analysis had a superior test sensitivity compared to the self-reports for most substances, including cocaine, ketamine, codeine, and possibly MDMA/ecstasy, underscoring the unique value of hair tests. Our comparison of the overall sample vs an optimal sample revealed no substantial differences, indicating that hair tests work well in real-life settings and that a proportion of about 80% of the participants who can provide a reasonable sample of head hair is sufficient. However, our results also agree with those from prior research suggesting that hair analysis has limited potential for detecting occasional exposure to cannabis[15,24] and that it performs relatively poorly in detecting amphetamine use.[22,24]

It is important to note that 11% of our participants did not agree to provide hair samples. Non-response in voluntary hair studies could be higher in populations and cultures with lower social acceptance of substance use or lower trust in research, which would lower a study's potential to determine the prevalence of substance use based on hair tests alone.

Correlates of Discordance

Our findings suggest that occasional substance use, as indicated by self-reported 1-time use and low levels of substances in hair, respectively, is associated with under- and overreporting. A considerable number of participants who underreported their substance use were willing to disclose their substance use, as indicated by their 12-month reports, but may have misremembered the timing of use (ie, recall bias). A prior study also indicated that misremembering substance use is more common among those who use substances less frequently.[28] That study associated a longer recall period with less accurate reporting. However, our findings suggest that even with short recall periods (eg, 3 months), it is useful to include effective memory bridges, a combination with longer periods (eg, 12 months), and graded response categories (eg, 1-time use vs more frequent use) to approximate the prevalence of substance exposure. These recommendations may also be relevant for everyday clinical practice. Young people who underreport their exposure to specific substances because they are unaware of or misremember it may also be prone to underreporting in medical consultations. This could, in turn, lead to dangerous drug interactions with prescribed medication.[48]

Positive 12-month self-reports among participants with a negative 3-month self-report despite a positive hair test could also indicate that these participants' hair had residue from substances consumed more than 3 months ago. Alternatively, some participants may have been exposed to substances without actively consuming them. Altogether, our findings suggest that resources for collecting additional self-reported information on substance use patterns or even hair data may be most efficiently allocated to studies on occasional substance use or transitions to heavier use, as participants with regular substance use tend to report their use more accurately.

Consistent with prior research,[22,23] our study found a correlation of socially unaccepted behaviors (ie, delinquency) with an increased likelihood of concordant positive self-reports and hair tests of cocaine use, compared to underreporting. Adding to previous evidence, our study also found a correlation of low self-control, ADHD symptoms, and internalizing symptoms with concordant positive self-reports and hair tests, compared to underreporting, for cocaine or codeine. Notably, the correlates of underreporting examined here were also self-reported, meaning that the associations could mirror tendencies toward coherent presentations of the self (eg, as someone with less socially desirable behaviors, including substance-use).[49] In addition, mechanisms of underreporting could be specific to each correlate. For example, individuals with low self-control could have fewer inhibitions about reporting personal information, including substance use, because they may not weigh the potential consequences. To adjust for response bias in self-reported substance use, researchers could control for self-reported (problem) behaviors and mental health variables, for example when analyzing health outcomes of substance use.

Finally, our results indicate that the risk of underreporting is largely equally distributed across social groups (eg, with different socio-economic and educational backgrounds) in the current sample and its context. However, our supplementary analyses indicated that future research must investigate further the associations between educational backgrounds and underreporting of non-medical use of prescription drugs.

Critical Review and Future Directions

Our study has several strengths. Combining self-reports with hair tests in a large community sample of young adults fills an important gap in substance use research. In addition, our data provide new insights into the (comparative) reliability of prevalence estimates for a variety of illicit substances and non−medically used prescription drugs. The analysis of the latter is an example of how self-reports and hair tests can directly complement each other (ie, self-reports of medical use are needed to qualify positive hair tests).

Nevertheless, our study also has limitations. First, individuals could have used substances medically first, but non-medically later (ie, in a different way, at a higher dose, or more frequently than prescribed or needed to treat their respective medical conditions). We were not able to identify incorrect self-reporting related to such overuse or misuse of medical substances. Second, although hair study participants did not differ from those who declined participation in the hair study in terms of self-reported substance use, non-participation in the hair study may be associated with the fear that inaccurate self-reports would be identified in hair. This could have resulted in biased estimates.

Third, we could not assess the self-reported 3-month prevalence of MDMA/ecstasy use due to a technical error. Fourth, the ketamine prevalence should be interpreted with caution, as ketamine can be ingested while consuming impure ecstasy pills.[50] In fact, 87% of the ketamine-positive hair samples in our study also contained MDMA. Fifth, although our sample was highly diverse in terms of parental migration background, the longitudinal design of the study precluded the recruitment of foreign-born young adults who had migrated to Switzerland after age 7 years (ie, the onset of the study in 2004).

Finally, it is unclear how our results generalize to other cultural settings and age groups. Future research based on community samples from other regions and with different socio-economic and cultural backgrounds is needed to replicate our findings or to provide context-specific factors to adjust prevalence and risk assessments of substance use. Furthermore, although we considered a number of mechanisms potentially underlying the discordance of self-reports and hair tests, future research is needed to examine additional mechanisms (eg, misunderstanding survey questions, lack of knowledge about specific medications and their ingredients) and whether the same mechanisms play a role in different populations. Since the prevalence of self-reported substance use typically increases between adolescence and young adulthood, including in our sample,[42,46,51] longitudinal research with hair tests is needed to examine whether test concordance and correlates of discordance change with age.

Our study suggests that self-report surveys underestimate the prevalence and burden of illicit substance exposure and non-medical use of prescription drugs among young adults, even in a setting that does not have harsh punishments for substance use. Hair data provided more reliable estimates than self-reported data for a variety of illicit substances and prescription drugs, including the most widely used ones (eg, cocaine, MDMA, opiates, and opioids). Furthermore, our findings indicate that the underlying mechanisms for underreporting are manifold, ranging from suspected misremembering of the timing of use, to accidental environmental exposure, to individual response patterns (eg, tendencies regarding the reporting of socially [un] desirable behaviors). These findings have implications for data collection methods, estimates of substance use prevalence, and predictive analyses in public health and developmental and clinical research.

As others have noted, both self-reports and biological testing can provide unique information on substance use.[52] Our study exemplifies that self-reports can be combined with hair toxicology analysis in large-scale community studies. Several specific characteristics of our sample may have contributed to the success of the data collection, including the long-term relationship established with the participants. If researchers are facing limited feasibility of hair sample collection (eg, due to lack of resources or trust among participants), they could collect hair from subsamples. Specifically, our findings suggest that a combination of self-reports with hair tests may be most beneficial in subsamples with presumably occasional substance use. Finally, researchers can adjust self-reported data of the prevalence and correlates of substance exposure with factors like those provided by our study.

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