

# Trends in Co-mention of Stimulants and Opioids: A Natural Language Processing Driven Analysis of Reddit Forums

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## Research Article

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# Abstract

## Background

Despite recent increasing focus on fatal overdoses involving multiple substances, there is a paucity of knowledge about stimulant co-use patterns among people who use opioids (PWUO) or people being treated with medication for opioid use disorder (PTMOUD). This study examines stimulant co-mention trends among PWUO/PTMOUD on social media.

## Methods

We collected publicly-available data from 14 prescription and illicit opioid and MOUD-related forums on Reddit (subreddits) between 2011-2020 and timelines comprising past posts from a sample of Reddit users (Redditors) on these forums. We applied natural language processing to detect mentions of opioids, opioid-related medications, and stimulants and described trends and patterns in co-mentions.

## Results

Posts collected for 13,812 Redditors indicated 12,306 (89.1%) mentioned  $\geq 1$  opioid, opioid-related medication or stimulant. Analyses showed the number and proportion of Redditors mentioning both opioids and/or opioid-related medications and stimulants steadily increased over time. Relative rates of co-mentions of heroin and methamphetamine, substances most commonly co-mentioned, decreased in recent years while those of fentanyl and MOUD with methamphetamine increased.

## Conclusion

Data from Reddit reflect increasing mentions of stimulants, particularly methamphetamine, among PWUO/PTMOUD and closely resemble the growth in overdose deaths involving both opioids and stimulants. These findings are consistent with recent reports suggesting increasing stimulant use among people receiving treatment for opioid use disorder. These data offer insights on emerging trends in the overdose epidemic and underscore the importance of scaling efforts to address co-occurring opioid and stimulant use including harm reduction and comprehensive healthcare access spanning mental-health services and substance use disorder treatment.

## 1. Background

Stimulant co-use<sup>1-3</sup>, specifically methamphetamine, and stimulant co-involvement in overdose fatalities<sup>4</sup>, including among people with opioid use disorder (OUD) are of growing concern in the US. This increase in co-use is likely contributing to statistically significant increases in overdose deaths involving both opioids and stimulants.<sup>5</sup> The rise in overdose deaths involving opioids and stimulants has exacerbated the challenge of addressing the decades-long opioid overdose crisis, and reflects the evolving, polysubstance nature of the broader overdose epidemic and the presence of illicitly manufactured fentanyl. Studies have shown that stimulant co-use exposes people who use opioids (PWUO) to

additional health risks, including overdose, infectious disease transmission, and suboptimal treatment outcomes.<sup>6,7</sup> Further, these changes in substance use patterns and related harms have occurred against the backdrop of a substantial increase in availability of methamphetamine across the US. Based on drug product submissions to the Drug Enforcement Administration's National Forensic Laboratory Information System, methamphetamine submissions more than doubled from 2011 to 2019.<sup>8</sup> In addition, in the 2020 National Drug Threat Assessment, methamphetamine seizures and price data as well as law enforcement reporting all indicate that methamphetamine is now readily available at a greater purity and potency throughout the US.<sup>9</sup>

Recent findings also suggest that reasons for co-use, particularly with methamphetamine, are multifaceted—such as ease of access, helping boost the “high”, improving daily function (e.g., increasing productivity or staying alert), and helping manage withdrawal symptoms.<sup>10</sup> However, little is known about when stimulants enter into the substance use trajectory of PWUO, how co-use patterns have shifted over recent years, and how patterns of opioid and stimulant co-use evolve at an individual-level. One potential source for gathering exploratory information on this emerging health concern is longitudinal social media data obtained from Reddit. Reddit data are being increasingly used for conducting observational research, particularly on sensitive topics such as substance use.<sup>14,16–18</sup>

### ***1.1 Objectives***

The overarching objectives of this study are to utilize social media conversation data on Reddit to:

- i. Estimate the volumes and short- and long-term trends of opioid-stimulant co-mentions
- ii. Quantify estimated co-use rates between pairs of specific opioids and stimulants based on these discussions
- iii. Identify when stimulants are initiated evidenced by mentions among PWUO at an individual level based on timelines of posts

The insights we derive in this study are purely data-driven through natural language processing (NLP) methods, as opposed to hypothesis-driven, and our methods account for growth in the number of Reddit users over time. A better understanding of the timing and patterns in stimulant co-use among PWUO as evidenced by mentions of these substances on social media can help inform prevention efforts including harm reduction, as well as future research directions. In the remainder of the article, we refer to people who post on specific subreddits of interest as Redditors; people who use or used prescription and/or illicit opioids, people who used an opioid reversal agent (e.g., naloxone), and people with OUD who are being treated with medications for opioid use disorder (MOUD) as PWUO/PTMOUD, people who use stimulants as PWUS, people who use drugs more broadly as PWUD, and people who co-use opioids and stimulants as PWCU.

## **2. Methods**

## **2.1 Data**

Reddit is particularly popular among PWUO and the broader community of people who use drugs (PWUD) as it can offer anonymity.<sup>11</sup> Reddit has seen rapid growth in its user base over the last several years. In 2021, it is estimated that Reddit has over 430 million<sup>12</sup> monthly active users (Redditors), surpassing the number of active Twitter users.<sup>13</sup> These increases may be driven by factors such as the organization of discussions through specialized topical-interest forums called *subreddits* and the moderation of forum-specific content by forum users. Reddit communities have also been found to serve as a means of social support for PWUD.<sup>14–16</sup>

To find potential PWUO on Reddit, we identified 14 opioid-related subreddits spanning discussions on prescription and illicit opioids, and MOUD (Appendix A1) and collected all retrievable posts contained using the Python-Reddit application programming interface (API) Wrapper for Reddit.<sup>19</sup> Since these subreddits serve as specific discussion forums for topics related to opioid use and recovery and empirical examination of posts revealed that most Redditors discussed personal use and experience, we assumed that all authors of posts that mentioned any opioid or opioid-related medications defined as opioid reversal agents and MOUD were either current or past PWUO/PTMOUD. We also assumed that mentions of a substance corresponded with presumed use of that substance. Thus, Redditors who mentioned opioids and/or opioid-related medications and stimulants were presumed to co-use both substances (PWCU) during the study period – in our analyses, we separately examined co-mentions of both substances within a given year as well as mentions that may have spanned multiple years. After retrieving subreddit posts of the 47,327 Redditors who had posted on the selected sub-reddits, we selected a random sample of these Redditors (N=13,812) and collected each of their past public posts across all subreddits (i.e., timelines), between November 2006 (corresponding to the earliest post available) and July 2021 (corresponding to the last date of data collection). Each timeline took approximately 20 minutes to obtain, so the number of Redditors included in the sample was limited by the rate at which we could collect full timelines via the API. We studied trends in opioid and stimulant co-use between January 1, 2011 and December 31, 2020. We excluded earlier years from this analysis because the numbers of posts (and correspondingly, Redditors) prior to 2011 were very low (i.e.,  $\leq 20$  posts), and we excluded 2021 because complete data for this year were not available. Due to similar concerns related to low posts with specific substances mentioned, we restricted our study of specific opioid and opioid-related medications, and stimulant categories to the years 2015 – 2020. We then chronologically ordered the posts per Redditor to enable an exploration of substance use timelines. All analyses described in this study were conducted using Python.

## **2.2 Identifying substance mentions**

We apply natural language processing methods to improve the detection of true mentions of opioids and stimulants, and to exclude false positives (e.g., negated concepts and ambiguous expressions). We focused the study on a set of common opioids, opioid-related medications, and stimulants, including both prescription and illicit types (Appendix A2). Since drug names and related expressions are often

misspelled on social media, we generated commonly used lexical variants of the terms using the LexExp tool.<sup>20</sup> We found that some non-standard terms and lexical variants tend to have high noise associated with them (i.e., expressions not actually referring to a stimulant or opioid, e.g., *oxy clean*). Thus, we included additional filters for the terms *stimulant*, *meth*, and *oxy* (Appendix A3). We applied an additional negation detection strategy, customized for Reddit data, to exclude negated drug mentions. Specifically, we used a subset of negation terms from the NegEx algorithm<sup>21</sup> (Appendix A4) with a moving context window, determined empirically, of size  $n = 5$  following the mention of a negation trigger. Any opioid, opioid-related medication, or stimulant term was considered negated if it appeared in the context window following a detected negation expression and if an end of sentence marker (e.g., a period) did not occur between the negation term and the drug term. Negated terms were excluded from the final count of mentions. We also manually reviewed samples of posts detected by our searches to identify keywords with a large amount of noise (e.g., '*dope*' for heroin and '*coke*' for cocaine) and excluded those from our counts and further analysis. Of the 13,812 Redditors sampled, a subset who posted in these subreddits had no mention of either an opioid, opioid-related medication, or a stimulant (N=1,506) and were excluded from the analyses. All analyses except for those examining the total numbers of redditors (including PWCU) over time were based on subsets of the remaining 12,306 Redditors who posted about at least one opioid, opioid-related medication, or stimulant.

### ***2.3 Opioid and stimulant co-use trends***

We first studied trends in opioid and stimulant co-use between 2011-2020 through multiple metrics, including, the number of Redditors posting each year; the number of Redditors who mentioned at least one opioid or opioid-related medication and one stimulant (i.e., PWCU) over the same time frame; and the annual ratio of PWCU to PWUO/PTMOUD . Due to the growing user-base of Reddit over time, we expected numbers of PWUO/PTMOUD and PWCU to both increase annually. Hence, the ratio of PWCU to PWUO/PTMOUD likely serves as the best indicator of social media trends in opioid and stimulant co-use within this population.

Next, we calculated and visualized three main explorations of co-use patterns for our dataset, focusing on the years 2015-2020 due to lower counts of posts by specific substances in prior years, – i) frequency of co-use of specific types of opioid-stimulant pairs among PWUO/PTMOUD aggregated over the entire study period; ii) proportion of specific opioids co-used with any stimulant in a given year among the total number of PWCU in that year, to study how mentions of specific opioids or opioid-related medications co-used with any stimulant changed over time; iii) proportion of specific stimulants co-used with any opioid or opioid-related medication in a given year among the total number of PWCU in that year, to study how mentions of specific stimulants co-used with any opioid changed over time. Redditors with mentions of more than one type of opioid or opioid-related medication or stimulant within a given year were separately considered for each specific opioid-stimulant pair.

We combined the opioids and opioid-related medications listed in our analytic sample into 5 categories: (i) heroin, (ii) fentanyl & analogs (including carfentanil), (iii) Medications for Opioid Use Disorder (MOUD);

*e.g.*, buprenorphine, methadone, naltrexone), (iv) opioid overdose reversal agents (*e.g.*, naloxone), and (v) prescription opioid pain relievers (*e.g.*, oxycodone, hydrocodone, and tramadol). We combined stimulants into 4 categories: (i) methamphetamine, (ii) amphetamine-type stimulants (*e.g.*, Adderall®, dextroamphetamine, levoamphetamine), (iii) methylphenidate-type stimulants (*e.g.*, Ritalin®), and (iv) a combination of methamphetamine and heroin (i.e., goofball/speedball). Categories included generic names, trade names, and common misspellings or lexical variants (Appendix A2). Due to aforementioned challenges of appropriately identifying keywords with substantial noise, we excluded mentions of cocaine from our analysis.

## ***2.4 Timeline analyses***

One of our objectives was to explore when stimulants are initiated and used by PWUO/PTMOUD over time. We focused specifically on methamphetamine initiation and use as our analyses revealed methamphetamine to be the most commonly used stimulant by a large margin (Appendix A5). We constructed a cohort by selecting the subset of Redditors who mentioned an opioid or opioid-related medication first in their timelines of posts from our randomly selected sample. To align the timelines of different Redditors, we considered the date of the first opioid mention to be Day 0. Timelines were stratified based on opioid type by grouping together Redditors who mentioned the same or similar opioids on Day 0. We tracked timelines for each PWUO/PTMOUD by computing the monthly frequencies of methamphetamine mentions for 24 months starting from Day 0. We excluded Redditors whose first and last post on Reddit were less than 24 months apart and those who had any stimulant-related posts within 30 days of their first opioid or opioid-related medication post (i.e., individuals with presumed co-use within the first month). By mapping the first post to Day 0 for all Redditors who posted, the distribution of posts over the 24 months was naturally skewed—each Redditor had at least one post in the first month, but the frequency of posts over the following months varied. To adjust for this, we normalized the monthly methamphetamine mention frequencies by the total posts made by PWUO/PTMOUD each month. Since most mentions correspond to personal use, we assumed Redditors with an opioid or opioid-related medication mention first and subsequent methamphetamine mention had transitioned to co-use. We developed heatmaps of these timelines to visualize temporal patterns of methamphetamine use.

# **3. Results**

## ***3.1 Study sample characteristics***

We collected 13,812 Redditor timelines from the 14 subreddits, 12,306 of whom mentioned at least one of our selected opioid, opioid-related medication or stimulant keywords. Redditors mentioning any opioid or opioid-related medication, or any stimulant in their timelines were approximately evenly distributed—9,329 Redditors mentioned opioids or opioid-related medication at some point in their timeline; 9,151 mentioned stimulants (Appendix A5). There was a substantial proportion of presumed PWCU among Redditors who mentioned at least one opioid, opioid-related medication or stimulant keyword – 6,174 (50.2%) Redditors mentioned both an opioid or opioid-related medication and a stimulant. However, there was a large

difference in the *first* substance mentioned – almost twice as many Redditors mentioned an opioid or opioid-related medication first in their timelines (n=8,276/12,306; 67.3%) versus those who mentioned a stimulant first (n=4,012/12,306; 32.6%).

### **3.2 Co-use characteristics**

Figure 1 shows the (a) total number of Redditors per year posting in the 14 opioid-related subreddits, (b) number of PWCU per year as defined by the number of persons posting about both opioids and stimulants within the same year, and (c) ratio of PWCU to total Redditors per year from 2011-2020 in our analytic sample. These metrics were computed independently each year, *i.e.*, a PWUO/PTMOUD or PWCU was determined based only on the posts within that year (Appendix A6 provides additional metrics). Figures 1a-b illustrates that the total number of Redditors posting on opioid-related subreddits (including Redditors with and without mentions of opioid or stimulant keywords of interest) as well as those posting about both opioids or opioid-related medications and stimulants (PWCU) increased each year since 2011, with sharp increases observed after 2016. The proportion of individuals posting about both opioids or opioid-related medications and stimulants as a fraction of all individuals posting also showed consistent annual growth (Figure 1c). By 2020, more than 15% of individuals posting in opioid-related subreddits had also posted about a stimulant.

Figure 2 shows heatmaps of the proportion reporting opioid and stimulant co-use among PWUO/PTMOUD. Within our sample, co-mentions of heroin and methamphetamine were most commonly observed relative to other opioid and opioid-related medications and stimulant types across 2011-2020. Indeed, across all opioids and opioid-related medications, methamphetamine was the most frequently co-mentioned stimulant. Amphetamine-type stimulants appeared to have the highest co-mentions after methamphetamine, followed by methamphetamine-heroin combinations (speedball/goofball). The relatively large volume of mentions of amphetamine-type stimulants was primarily driven by discussions of Adderall®, a prescription stimulant (Appendix A5). Interestingly, amphetamine-type stimulants appeared to have the highest probability of co-use with prescription opioid pain relievers (*e.g.*, hydrocodone and oxycodone) relative to illicit opioids such as heroin.

### **3.3 Co-use over years**

Figure 3 shows the proportion of individuals who posted about particular opioid-related categories among those posting about both opioids and stimulants within a given year. This helps illustrate which opioid-related categories were most commonly mentioned among PWCU and how mentions of these opioids and opioid-related medications in the setting of co-use have potentially changed over time – *e.g.*, fentanyl and its analogs had a relatively low probability of being discussed with stimulants in 2015, but nearly doubled by 2020. Mentions of MOUD similarly increased while those of heroin decreased over time among PWCU.

Figure 4 shows the proportion of individuals posting about a particular stimulant among all individuals posting about both opioids or opioid-related medications and stimulants that same year.

Methamphetamine mentions largely eclipsed all other stimulants studied. Amphetamine-type stimulants showed the next highest co-use and increase over time.

### **3.4 Timeline analysis results**

Figure 5 illustrates the initiation of and patterns in methamphetamine mentions among the cohort of individuals who first mentioned opioids. Overall, 849 Redditors from our sample met the inclusion criteria (*i.e.*, had posts spanning >24 months, first mentioned an opioid or opioid-related medication, and no stimulant posts prior to or <30 days of first opioid post) with a total of 4,303 posts. Specifically, our figures show 24-month heatmaps where each month displays the relative frequencies of methamphetamine mentions normalized by the total number of posts made by PWUO/PTMOUD in that month. The heatmaps are stratified by the first opioid or opioid-related medication type the individual posted about in their timeline.

There are observable differences between the heat maps associated with the different types of opioids. The heatmap for *heroin* suggests co-use discussions with methamphetamine occurred most frequent relatively early in PWCU timelines. Conversely, the *fentanyl & analogs* heatmap shows a different pattern—methamphetamine co-use for these individuals demonstrates periods with elevated discussions at the beginning, middle, and end of the 24-month timeline. Heatmaps for *prescription opioid pain relievers* and *MOUD* were similar, with higher methamphetamine mentions at the beginning of the timelines and decreases toward the end; however, these decreases in mentions were smaller in magnitude relative to decreases among individuals who initially discussed heroin.

## **4. Discussion**

The findings from our analysis of social media data are consistent with those from traditional health data sources indicating increased opioid and stimulant co-use over time<sup>3,6</sup>, while also offering unique exploratory insights. While the opioid overdose epidemic has been ongoing for over a decade now, the surge in stimulant use, in particular methamphetamine use, among PWUO is a relatively recent public health concern. Several hypotheses have been suggested to explain this growing trend, including efforts to improve prescribing practices to reduce the availability of opioids<sup>3</sup> which may have resulted in shifts to other substances by PWUO, increased accessibility and popularity coupled with low costs of stimulants,<sup>3</sup> using stimulants to manage or reduce opioid withdrawal symptoms, and co-using stimulants for synergistic euphoric effects.<sup>10,22</sup>

When examining the most frequently co-mentioned substances between 2011-2020, we found illicit opioids were more frequently mentioned with illicit stimulants (e.g., heroin and methamphetamine) and prescription opioids were most frequently mentioned with prescription amphetamine-type stimulants (*e.g.*, oxycodone/hydrocodone and Adderall®). This suggests possibly distinct populations within the social media substance use forums we studied with preferences for particular types of substances. Further understanding the distinction between populations focused primarily on prescription



drug misuse and those focused on illicit substance use, and the transitions between these preferences, is a future area for exploration of online data that may yield insights for better targeting prevention and harm reduction efforts. Indeed, while there is research on prescription stimulant misuse<sup>24</sup>, less is known about its relationship to substance use trajectories, especially among individuals who misuse prescription opioids.<sup>23</sup>

We found noticeable increases in the proportion of stimulant mentions among individuals also discussing MOUD over time, consistent with recent reports indicating that stimulant use among people receiving treatment for OUD may be increasing.<sup>2,25</sup> Co-use of stimulants among people with OUD is concerning given prior research demonstrating increased risk for health harms such as overdose as well as suboptimal treatment outcomes, including poorer retention in MOUD, among people with OUD who use stimulants.<sup>26,27</sup> These findings together underscore the importance of scaling efforts to address co-occurring opioid and stimulant use through expansion of MOUD in combination with nonpharmacological treatment modalities that address stimulant use such as contingency management and community reinforcement approach or cognitive behavioral therapy, along with recovery support services.<sup>28</sup>

Interestingly, while relative rates of stimulant co-use among individuals using fentanyl appear to be on the rise, the relative rate for co-use among individuals using heroin showed a gradual decrease. This is perhaps a result of changes in the illicit opioid supply over recent years, as heroin has experienced supply shortages<sup>29 30</sup> and the illicit drug market in many communities has transition from a heroin-based market to a fentanyl-based market.<sup>30</sup> For persons using stimulants to counteract the depressant-type effects of opioids,<sup>31</sup> the stronger potency of fentanyl may also be driving increased interest in stimulant use. Recent literature also suggests that PWUO/PTMOUD who knowingly or unknowingly consume fentanyl, tend to have more severe withdrawal symptoms when taking MOUD,<sup>32</sup> which may partially explain the greater interest over time in stimulants among Redditors discussing both MOUD and fentanyl. Our results suggest that as availability and use of synthetic opioids such as fentanyl continue to increase, interest in and co-use of stimulants could persist. Individuals with polysubstance use have unique treatment needs and have higher risks for mental-health comorbidities,<sup>33</sup> further emphasizing the need for increased availability of comprehensive healthcare including mental-health services and substance use disorder treatment for PWUD. Qualitative research is needed to help better characterize timing and concerns associated with initiation of co-use among PWUO in order to develop and appropriately direct prevention and response strategies that can address the needs of this population.

#### **4.1 Limitations**

Our study has several limitations. Absent contextual information, the primary limitation is the assumption that an individual mentioning an opioid, opioid-related medication or stimulant is currently using that substance, which may result in overestimation of the number of PWUO/PTMOUD, PWUS, and PWCU, particularly in analyses where these mentions spanned multiple years. Nonetheless, the number of

mentions could be a proxy for use and at minimum, mentions of a substance represent some degree of interest or consideration of a particular substance. Also, since the forums from which the Redditors were initially identified are topic-specific, most posts explicitly or implicitly refer to personal experiences. Second, individuals who post on Reddit may not necessarily be representative of all PWUD and caution when generalizing from these findings is warranted. According to a 2019 PEW Research Center report, Reddit has an overrepresentation of males and younger people.<sup>34</sup> Since then, however, the user base on Reddit has grown significantly. Third, not all PWUO, PWUS and PWCU necessarily mention all the substances they may use. Additionally, we excluded cocaine from our analyses due to challenges associated with accurately identifying mentions. Further, our analyses were limited to opioid-related subreddits and excluded any stimulant-related subreddits given our focus on PWUO/PTMOUDs. These limitations may both lead to an underestimation of stimulant and opioid-stimulant co-use. Fourth, we were only able to conduct our analyses on a sample of Redditors due to the rate limitations of the API. Our concerns about this limitation are mitigated by the finding that statistics derived from smaller samples of Redditors early on in our study remained almost identical to those obtained when larger numbers of individuals were included. The exponentially rising number of Reddit subscribers over time also posed a challenge for us, since we could not quantify how much of the increasing opioid or opioid-related medications and stimulant mentions could be attributed to increases in their use in the community versus the growing Redditor numbers. To address this, we examined the ratio of PWCU to Redditors, which revealed that the growth rate in substance mentions was higher than the growth rate of Redditors. It is possible that other factors contributed to the rising substance mention rates, but we were unable to include such confounding factors in this analysis. Lastly, methodological limitations inherent to all analyses of unstructured text data apply as not all mentions/expressions are detectable by NLP methods.<sup>35,36</sup> However, we employ robust and well-validated approaches for capturing spelling variants and non-standard expressions.

## 5. Conclusion

We examined real-world, longitudinal social media data from online opioid-related forums to explore patterns in opioid and stimulant discussions and found large increases in co-mentions of opioids or opioid-related medications and stimulants. These findings are consistent with those from other health data sources suggesting growing co-use of these substances and resultant harms. Although a multitude of factors may influence substance use trends, many are difficult to elucidate and explore using traditional data sources such as survey records or health care data. The social media data we explored offers important exploratory insights into which opioids or opioid-related medications and stimulants are most frequently co-mentioned and how these patterns have changed over time. These data derived from real world conversations may help in hypothesis generation and yield early insights to shape prevention activities addressing health harms associated with opioid and stimulant co-use.

## Abbreviations

PWUO: people who use opioids

PTMOUD: people being treated with medications for opioid use disorder

OUD: opioid use disorder

MOUD: medication for opioid use disorder

NLP: natural language processing

PWUD: people who use drugs

PWCU: people who co-use (opioids and stimulants)

PWUS: people who use stimulants

API: application programming interface

## **Declarations**

### **Ethics approval and consent to participate**

This study was approved by the Emory University Institutional Review Board (IRB). The study was deemed to fall under exemption category 4 (publicly available data). Consent from Reddit subscribers was not sought since the data is publicly available. No identifiable information is presented in the paper.

### **Consent for publication**

N/A

### **Availability of data and materials**

All posts used in this study were publicly available at the time of collection. Data can be collected via the API mentioned in the article. Aggregated statistics presented in the paper will be shared by the authors upon request.

### **Competing interests**

None declared.

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## Authors' contributions

AS performed the primary data analysis and interpretation, and authored the original draft of the manuscript. MAA and YG assisted AS with the data collection, analysis and presentation, including the statistical analysis and the generation of figures. NN, CMJ and SAS contributed to the data analysis and interpretation, and performed substantial revisions to the manuscript. CMJ and SAS provided domain expertise and high-level guidance for the study, and contributed to critical revisions. All authors contributed to the writing of the manuscript and approved the final version.

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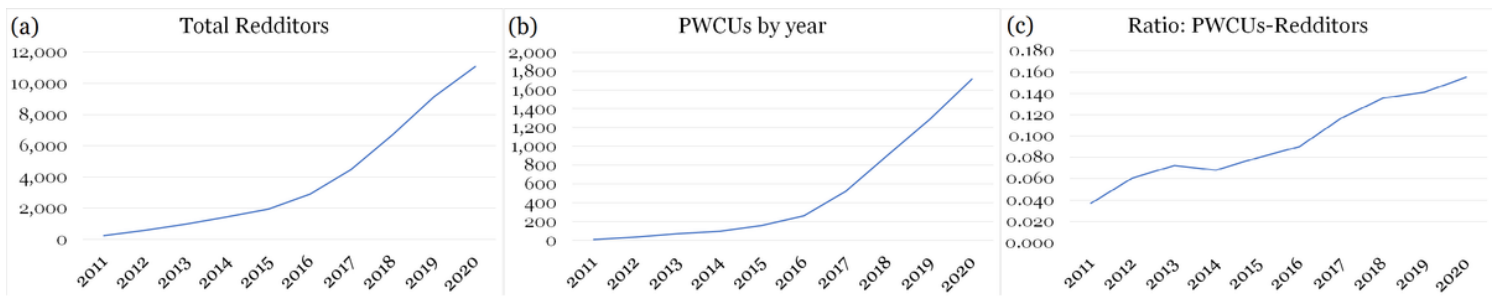
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## Figures



**Figure 1**

(a) Total number of Redditors who posted in the opioid-related subreddits each year from 2011 to 2020; (b) total number of people who co-use opioids and stimulants (PWCUs), i.e., who posted about both opioids and/or opioid-related medications and stimulants; (c) ratio of PWCUs to total number of Redditors each year.

**Figure 2**

Proportions of Redditors who posted about specific opioid and opioid-related medication and stimulant pairs (*e.g.*, opioid *i* and stimulant *j*) among all Redditors who posted about each specific opioid or opioid-related medication (*e.g.*, opioid *i*). Opioids, opioid-related medication and stimulants are grouped as described in section 2.3. Total number of Redditors who mentioned at least one opioid = 9,329. Total number of Redditors who mentioned at least 1 stimulant = 9,151.

**Figure 3**

Proportions of people who co-use opioids and stimulants (PWCUs, N = 4,786) who mentioned co-use of specific groups of opioids or opioid-related medications with any stimulant by year from 2015 – 2020. Total number of unique people who use opioids (PWUO)/ people with OUD who are being treated with medications for opioid use disorder (PTMOUD) within this timeframe = 8,831. Opioid-related categories – Fentanyl and analogs (fentanyl and carfentanyl); Heroin; Medications for opioid use disorder (MOUD: suboxone, sublocade, methadone, buprenorphine, naltrexone); Opioid reversal agents (Naloxone); Prescription opioid pain relievers (hydrocodone, oxycodone, morphine, tramadol).

## Figure 4

Proportions of people who mentioned co-use of specific groups of stimulants with any opioid or opioid-related medication (PWCU, N = 4,786) by year from 2015 – 2020. Total number of people who use stimulants (PWUS) within this timeframe = 8,266. Stimulant categories – Amphetamine type stimulants (amphetamine, dextroamphetamine, levoamphetamine, and lisdexamphetamine); Methamphetamine; Methylphenidate type stimulants (methylphenidate); a combination of methamphetamine and heroin (Speedball/Goofball).

## Figure 5

24-month (excluding the first month) monthly relative frequencies of methamphetamine mentions among Redditors who first mentioned an opioid or opioid-related medication (N = 849). Mention frequencies per month are normalized by the total number of posts by the same set of Redditors within that specific time span. Opioid-related categories – Fentanyl and analogs (fentanyl and carfentanyl); Heroin; Medications for opioid use disorder (MOUD: suboxone, sublocade, methadone, buprenorphine, naltrexone); Opioid reversal agents (Naloxone); Prescription opioid pain relievers (hydrocodone, oxycodone, morphine, tramadol). Stimulant categories – Amphetamine type stimulants (amphetamine, dextroamphetamine, levoamphetamine, and lisdexamphetamine); Methamphetamine; Methylphenidate type stimulants (methylphenidate); a combination of methamphetamine and heroin (Speedball/Goofball).

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