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Combining ecological momentary assessment with objective, ambulatory measures of behavior and physiology in substance-use research

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HIGHLIGHTS

- It is important to understand the momentary contextual determinants of drug use.
- Mobile technologies can assess participants and their environments during daily life.
- Progress has been made combining self-report, multiple sensors, and machine learning.
- Challenges include participant burden, device functionality, and data processing.
- Mobile assessment is leading to mobile intervention, including prediction/preemption.

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ABSTRACT

Whereas substance-use researchers have long combined self-report with objective measures of behavior and physiology inside the laboratory, developments in mobile/wearable electronic technology are increasingly allowing for the collection of both subjective and objective information in participants' daily lives. For self-report, ecological momentary assessment (EMA), as implemented on contemporary smartphones or personal digital assistants, can provide researchers with near-real-time information on participants' behavior and mood in their natural environments. Data from portable/wearable electronic sensors measuring participants' internal and external environments can be combined with EMA (e.g., by timestamps recorded on questionnaires) to provide objective information useful in determining the momentary context of behavior and mood and/or validating participants' self-reports. Here, we review three objective ambulatory monitoring techniques that have been combined with EMA, with a focus on detecting drug use and/or measuring the behavioral or physiological correlates of mental events (i.e., emotions, cognitions): (1) collection and processing of biological samples in the field to measure drug use or participants' physiological activity (e.g., hypothalamic-pituitary-adrenal axis activity); (2) global positioning system (GPS) location information to link environmental characteristics (disorder/disadvantage, retail drug outlets) to drug use and affect; (3) ambulatory electronic physiological monitoring (e.g., electrocardiography) to detect drug use and mental events, as advances in machine learning algorithms make it possible to distinguish target changes from confounds (e.g., physical activity). Finally, we consider several other mobile/wearable technologies that hold promise to be combined with EMA, as well as potential challenges faced by researchers working with multiple mobile/wearable technologies simultaneously in the field.

1. Introduction

Technological advances are opening new frontiers in ecological momentary assessment (EMA). Paper diaries and questionnaires have given way to electronic versions delivered on smartphones that can timestamp and wirelessly upload entries. Mobile/wearable technology has also expanded the capacity to collect concurrently with real-time self-report a broad range of other types of data, such as biological samples, location, and physiological changes. This technology is enabling researchers to study substance use "in the moment," monitoring both the individual and the environment to better understand its causes and consequences.

In this paper we review studies of substance use that combine EMA with objective measurements in the field. It has long been common in

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Table 1
Field studies of substance use combining EMA with the field collection of participants' biological samples.

Reference	Substance(s)	Measure added to EMA	Participants	Monitoring duration	EMA device; other device(s)	Compliance/Feasibility	Notes
Garrison et al., 2015	Tobacco	Breath carbon monoxide (CO)	140 adult smokers with motivation to quit	22 days	Apple iPhone or Android smartphone; piCO$^+$ Smokerlyzer	N/A	Protocol for planned/ongoing study; CO monitoring for verifying abstinence after 6 months
Linas et al., 2016	Opioids, cocaine	Sweat collection	109 adults with recent heroin or cocaine use	30 days	Palm Z22 PDA or Motorola Droid X2 smartphone; PharmChek sweat patch	Evaluable EMA data on 97% of participant-weeks; 91% of sweat patches returned	Sweat collected in the field for subsequent laboratory-based analysis
Simons et al., 2015	Alcohol	Transdermal alcohol	60 young adults (aged 18–25 years) with at least moderate drinking	3 × 1–2-week "bursts," 1 per academic semester	Palmtop computer (model N/A); Giner WrisTAS 7 alcohol sensor	82% EMA response rate; WrisTAS worn with no sensor failure on ~72% of days	

laboratory studies to combine self-report with objective measures; doing so in daily life is an important step forward. Objective measures can help confirm EMA entries, but they also provide unique insight into the spatiotemporal organization of mood and behavior and allow for novel tests of longstanding theories (e.g., about environmental influences on mood and drug use).

As the field develops, systematic reviews and meta-analyses will be needed to assess specific hypotheses. In this review, our aims are simply to introduce investigators to available techniques and to help mobile/wearable device developers combine their work with EMA.

2. Field collection/processing of biological samples

2.1. General considerations

Table 1 presents a summary of studies combining EMA with the field collection of biological samples in studies of substance use. Field collection of blood and urine, the biological matrices most commonly used in studies of substance users, presents challenges in terms of safety and participant acceptability. More progress has been made with breath, perspiration, and oral fluid/saliva. Other samples could be collected in the field (e.g., hair and nails, Krumbiegel et al., 2016); the time-frames of the information obtained from these may be less appropriate for matching with EMA reports, but they may be appropriate for characterizing longer-term patterns (Cooper et al., 2012; Short et al., 2016).

Field monitoring may be particularly important for drugs with short windows of detectability or for drug-using situations that impede accurate self-reporting (e.g., Luczak & Rosen, 2014; Simons, Wills, Emery, & Marks, 2015). The latter include drug mixtures (e.g., alcoholic cocktails, many street-purchased drugs), especially those prepared by another person, as well as communal sources (e.g., a shared pipe). Depending on the technique, biological monitoring can reduce burden and maintain the naturalism of the use experience: it need not interrupt the normal "flow" of behavior as answering an EMA questionnaire does. Field detection of drug use may also be important for monitoring adherence to pharmacotherapies. Finally, studies of substance use may benefit from field monitoring of endogenous substances, including salivary cortisol as an indicator of hypothalamic-pituitary-adrenal (HPA) axis activity, as well as salivary alpha amylase and salivary flow rate as indicators of autonomic activity (for their combination with EMA in other populations, see e.g., Skoluda, Linnemann, & Nater, 2016; Strahler & Nater, 2017; Van Lenten & Doane, 2016).

In choosing biological matrices and analyte(s), researchers should consider how they will verify the source, timing, and integrity of the sample, as well as whether sample collection will be time-based and/or event-based (Kudielka, Gierens, Hellhammer, Wüst, & Schlotz, 2012). It is also necessary to distinguish between techniques that collect samples in the field for later processing in the laboratory versus live processing. Several types of field collection of biological samples (without field processing) relevant to mHealth studies of substance use have been performed: collection of liquid perspiration to detect opioid and cocaine use in combination with EMA (Linas et al., 2016) or to detect alcohol without EMA (Phillips & McAloon, 1980, but see also Phillips, Little, Hillman, Labbe, & Campbell, 1984); collection of saliva/oral fluid to detect smoking in studies of mobile interventions (Abroms, Boal, Simmens, Mendel, & Windsor, 2014; Free et al., 2011); and collection of saliva/oral fluid for cortisol measurement in smokers and other substance users (al'Absi, Hatsukami, Davis, & Wittmers, 2004; al'Absi, Carr, & Bongard, 2007; Direk, Newson, Hofman, Kirschbaum, & Tiemeier, 2011; Lovallo, Dickensheets, Myers, Thomas, & Nixon, 2000; Sorocco, Lovallo, Vincent, & Collins, 2006; Steptoe & Ussher, 2006; see also Bauer et al., 2011). Although not yet performed with substance users specifically (see al'Absi et al., 2004, 2007 for paper questionnaires completed in the field), to our knowledge, EMA has been successfully combined with the field collection of salivary cortisol in other