Addictive Behaviors xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Addictive Behaviors

journal homepage: www.elsevier.com/locate/addictbeh

The use of ambulatory assessment in smoking cessation

Christine Vinci[a,*], Aaron Haslam[b], Cho Y. Lam[c], Santosh Kumar[d], David W. Wetter[c]

[a] Moffitt Cancer Center, USA
[b] Texas Tech, USA
[c] University of Utah, USA
[d] University of Memphis, USA

HIGHLIGHTS

- Brief overview of EMA for smoking cessation
- Discussion of how lab-based techniques are being used in the real world.
- Use of wearable wireless sensors in smoking cessation research
- Detailed discussion of cessation intervention opportunities via wearables
- Challenges and limitations of sensor-based tools in cessation research

ARTICLE INFO

Keywords:
Ambulatory assessment
Smoking cessation
Wearable technology

ABSTRACT

Ambulatory assessment of smoking behavior has greatly advanced our knowledge of the smoking cessation process. The current article first provides a brief overview of ecological momentary assessment for smoking cessation and highlights some of the primary advantages and scientific advancements made from this data collection method. Next, a discussion of how certain data collection tools (i.e., smoking topography and carbon monoxide detection) that have been traditionally used in lab-based settings are now being used to collect data in the real world. The second half of the paper focuses on the use of wearable wireless sensors to collect data during the smoking cessation process. Details regarding how these sensor-based technologies work, their application to newer tobacco products, and their potential to be used as intervention tools are discussed. Specific focus is placed on the opportunity to utilize novel intervention approaches, such as Just-In-Time Adaptive Interventions, to intervene upon smoking behavior. Finally, a discussion of some of the current challenges and limitations related to using sensor-based tools for smoking cessation are presented, along with suggestions for future research in this area.

The ambulatory assessment of smoking behavior has greatly evolved over the last several decades and continues to do so through advances in technology. The data gathered via ambulatory assessment has the potential to not only contribute to the development of efficacious cessation interventions, but also to the larger theoretical literature on smoking behavior and relapse. Ambulatory assessment can aid in "filling in the blanks" regarding what happens in a real-world setting (i.e., outside of the laboratory) prior to an individual picking up a cigarette to smoke. These data are vital to advancing theories on smoking relapse, as the current state of our models provide little guidance on the complex temporal patterns of mood and relapse, and the general relationships that exist moment-to-moment among key relapse variables. For example, we know motivation is a key factor in behavior change and that individuals may change their intentions to quit smoking on a daily basis (Hughes, Keely, et al., 2005; Hughes, Solomon, Fingar, Helzer, & Callas, 2013; Peters & Hughes, 2009). However, we do not have strong theoretical models to guide how an intervention should be developed and implemented based on these daily, or even more frequent, motivational fluctuations in order to prevent relapse. Further, it is not clear how other key variables in the cessation process (e.g., negative affect, self-efficacy) may influence or be changed by a momentary intervention targeting motivation. As such, collecting and examining data via ambulatory assessment provides the opportunity to inform theoretical models of change for smoking cessation that will have implications for relapse prevention.

Aside from theory, ambulatory assessment can have a direct impact

* Corresponding author at: Moffitt Cancer Center, Health Outcomes and Behavior, 4115 E Fowler Ave., Tampa, FL 33617, USA.
E-mail address: christine.vinci@moffitt.org (C. Vinci).

https://doi.org/10.1016/j.addbeh.2018.01.018
Received 30 June 2017; Received in revised form 12 January 2018; Accepted 15 January 2018

on intervention development. For example, although we know that negative affect is a key trigger for relapse, it is not clear how fluctuations in negative affect may interact with an individual's self-efficacy for quitting. If a cessation intervention is able to slowly increase self-efficacy for quitting over the first few days of a quit attempt, will a spike in negative affect on day 3 of the quit attempt be a huge risk for relapse? Should the intervention also target negative affect? If so, does the timing of delivery of the negative affect component of the intervention matter? Capturing how these variables interact and shift hour-to-hour, minute-to-minute via advances in ambulatory assessment will allow us to intervene at the most opportune time to prevent relapse. Much of this future work will be shaped by advances in technology, including the ability to monitor and intervene upon behavior via wearable devices.

This paper will provide a brief overview of the history of ambulatory assessment as related to smoking behavior with a primary emphasis on smoking cessation, as many other papers have described this topic in great detail (Shiffman, 2014; Shiffman, Stone, & Hufford, 2008; Stone & Shiffman, 1994). The paper then shifts to discuss current and future applications of ambulatory assessment, with a particular focus on the role of wearable sensors and its potential to influence how smoking behavior is captured and intervened upon.

1. Ecological momentary assessment

Early research on smoking behavior and cessation primarily relied on retrospective recall at clinic visits. That is, participants would attend an in-person clinic visit and be asked something along the lines of "What caused you to lapse?" or "What was your mood like when you lapsed?" Although these data provided insight into the smoking cessation process, the limitations of retrospective recall are numerous. Previous work has discussed these issues in detail (Shiffman et al., 2008). One method for addressing the limitations of studies that rely on retrospective recall is to use ecological momentary assessment (EMA). EMA consists of a variety of methods designed to assess phenomena closer to real time in the real world by having participants monitor their daily activities (Shiffman, 2009). Two commonly used forms of EMA in the smoking cessation literature are daily diary studies and studies that consist of multiple daily assessments. It should be noted that daily diary studies are sometimes captured under other terms used to describe ambulatory assessments (e.g., experience sampling). Here we have decided to discuss daily diaries under the umbrella of EMAs, consistent with the EMA tobacco use literature (Shiffman, 2009; Shiffman et al., 2008).

Daily diary studies usually involve asking participants to complete a set of questions one time per day, and data may be collected in a paper and pencil format or through prompts sent on a smartphone. Diaries are typically completed at the same time of day for the duration of the study, and ask participants various questions that may summarize their day (e.g., How many cigarettes did you smoke today? Rate your level of sadness over the past 24 h.). These questions may be asked over several days or weeks to capture what is occurring on a daily basis during the smoking cessation process.

Another type of EMA design involves having participants report their current behavior multiple times per day. Data are often collected via a hand held device (e.g., smartphone) by sending participants multiple prompts throughout the day. A much richer source of data is gathered through this design relative to others (i.e., daily diary, longitudinal, and cross-sectional), as the ability to prospectively examine within-person changes in variables important to smoking within the same day becomes available (Lam et al., 2014; Vinci et al., 2017).

2. Smoking topography and carbon monoxide

Other types of ambulatory assessment somewhat unique to the field of smoking include the collection of smoking topography and carbon monoxide. Smoking topography involves measuring smoking behavior by having the participant smoke a cigarette through a smoking topography device. The device stores data such as number of puffs taken, time to smoke a puff, interpuff intervals, puff duration, puff velocity, and puff volume (CReSS; Plowshare Technologies, Baltimore, MD, USA). Smoking topography studies provide useful information on the relationship between smoking behavior and smoking cessation, and topography has been measured in settings outside of the laboratory. Prior work has examined smoking topography in the real world to determine differences in smoking patterns among groups of people (e.g., chippers vs dependent smokers; Brauer, 1996; Korean American vs White men; Chung et al., 2015). Research has also shown that self-reported cigarettes smoked per day were not associated with smoking topography patterns in day-to-day life (Hatsukami, Morgan, & Pickens, 1987). That is, people who reported smoking more cigarettes per day did not necessarily demonstrate more intense smoking behavior via topography device in the real world, and vice versa. Such findings have multiple implications, including the applicability to withdrawal symptoms experienced during a quit attempt, as people who smoke more cigarettes per day may not necessarily be more physically dependent on tobacco.

Measuring level of carbon monoxide (CO) in smoking cessation studies is a valuable source of objective data regarding abstinence outcomes. For instance, the seven day point prevalence of smoking is commonly used as an abstinence outcome in cessation studies, which is the self-report of no smoking in the past seven days, combined with a CO reading of less than some predefined level of CO in parts per million (ppm; Benowitz et al., 2002). Although CO readings are typically conducted in-person at clinic visits, mobile, phone-based CO readers have been developed (Meredith et al., 2014). The ability to use a portable CO monitor can greatly reduce participant burden of traveling to the clinic during cessation studies to confirm abstinence status. Further, Meredith et al. (2014) found that this device was rated as highly useable and acceptable among their sample of participants, which were low socioeconomic status (SES) smokers (i.e., majority with no college education and an income of less than $200 per month). Although an initial concern of mobile CO readers may be the inability to confirm who submitted the sample, Dallery, Raiff, and Grabinski (2013) have developed a web-based application that allows individuals to take CO readings at home, all while monitoring the process via webcam to confirm that the correct person has provided the sample. In fact, this technology has been taken one step further to allow for mobile-based CO readings that also have a video component to confirm the user (Hertzberg et al., 2013). Initial findings have deemed compliance to this technology as excellent (Hertzberg et al., 2013).

3. Wireless wearable sensors

As ambulatory assessment has continued to advance, there has been an increase in the development of wearable wireless sensors. These devices are worn somewhere on the body, such as the wrist, ankle, or chest. Although a variety of sensors have been developed for the measurement of a multitude of behaviors, this section primarily focuses on those specific to smoking behavior. The detection of smoking behavior in the real world in real time is incredibly important when studying smoking lapse and relapse. Prior to wearable sensors, researchers had to rely on participant self-report of smoking. However, recent developments in technology have allowed the objective and unobtrusive detection of smoking behavior without participant volition (i.e., the participant self-reporting their smoking status).

An example of wearable wireless sensors is AutoSense (Ertin et al., 2011). AutoSense consists of a chest band that detects physiological measures of electrocardiogram (ECG), respiration, galvanic skin response, skin temperature, and accelerometer data from participants. Real time smoking behavior can be estimated when the data from these sensors is combined with data collected from wrist-worn sensors (that