Published in final edited form as:

Adolesc Psychiatry (Hilversum). 2013 April 1; 3(2): 156–162. doi:10.2174/2210676611303020006.

The Remote Monitoring of Smoking in Adolescents

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Abstract

Background/objectives—Cigarette smoking remains the leading cause of preventable death in the United States with the vast majority of adult smokers starting prior to the age of 18. Despite the public health relevance and implications of studying smoking in adolescents, little is known about the initiation of quit attempts, the process of relapse, and the most efficacious treatment interventions in this high-risk and underserved population. Issues such as retention in research studies and accuracy of self-reports have prompted investigators to explore innovative technology-based systems to integrate into treatment studies and services delivery.

Methods—This paper will review the remote monitoring of smoking through means of ecological momentary assessment, biochemical verification of smoking verified through video capture, physiological monitoring, and mobile-delivered interventions using self-reported smoking outcomes in adolescents, when applicable.

Results—Use of remote monitoring methods in adolescent smokers has been limited thus far, though monitoring technology in adults has shown promise for understanding relapse and delivering treatment interventions.

Conclusions—Comprehensive technology-based systems that do not rely primarily on self-report to monitor smoking would be a highly fruitful and innovative avenue to explore with adolescent smokers. Technology integration holds great promise to improve health-related research, treatment delivery, cost-effectiveness, and just-in-time interventions, but its novelty comes with unique problems and concerns to be carefully considered.

Keywords

adolescents; mHealth; relapse; remote monitoring; smoking cessation; technology; tobacco

Technology integration into research and healthcare delivery holds the potential for vast improvements to patient outcomes. This review will be devoted specifically to technology integration for the research and treatment of adolescent smoking, which has significant public health relevance, with emphasis on the emerging field of mobile health (mHealth).

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CONFLICTS OF INTEREST The authors have no conflicts of interest to disclose.

We will also briefly discuss the implications of mHealth for other aspects of adolescent health promotion.

Mobile Health

MHealth is generally considered to be any health-related services delivered through mobile devices (Vital Wave Consulting, 2009). MHealth is an emerging area of innovation, research, and dissemination that incorporates mobile technology, such as mobile devices, health-related applications (apps) for mobile platforms, remote monitoring, body sensors, etc. The goal of this work is to improve health-related research, treatment delivery and fidelity, frequency of data collection, dissemination, just-in-time interventions, respondent burden and cost-effectiveness. This area is especially exciting for use with adolescents, who show high rates of technology utilization, acceptability, and comfort, and also present a number of unique challenges in health-related research, such as poor treatment outcomes, adherence, and retention, which could be improved with mobile technology.

CIGARETTE SMOKING IN ADOLESCENTS

Cigarette smoking remains the leading cause of preventable death in the United States, with smoking-related healthcare expenditures and lost productivity reaching approximately \$193 billion (Centers for Disease Control, 2008), representing arguably the most significant public health concern of our time. The vast majority of adult smokers (88%) began smoking prior to the age of 18 (Surgeon General's Report, 2012), and tobacco use in adolescence reliably predicts being a smoker as an adult, leading to a life expectancy 20 years shorter than nonsmokers (Backinger, Fagan, Matthews & Grana, 2003; Chassin, Presson, Sherman & Edwards, 1990). Adolescent smoking rates range from 4.3% of middle school students to 15.8% of high school students (Backinger et al., 2003; Surgeon General's Report, 2012), while 34.2% of youth between the ages of 18-25 endorse current smoking (Substance Abuse and Mental Health Services Administration, 2011). Nearly two-thirds of adolescent smokers are interested in quitting, and 77% reported making a serious quit attempt in the past year (Hollis, Polen, Lichtenstein & Whitlock, 2003), but only 4-6% of unassisted quit attempts were successful (Chassin, Presson, Pitts & Sherman, 2000; Stanton et al., 1996; Zhu et al., 1999). The few well-controlled studies to date that have evaluated youth smoking cessation programs do not perform much better, and generally show exceedingly poor outcomes. For example, a meta-analysis of 48 studies showed a mean quit rate of 9.1%, compared with 6.2% among control groups (Sussman, Sun & Dent, 2006).

Relapse is a substantial hurdle to long-term abstinence from smoking and the most likely outcome of a quit attempt. Approximately 92% of young smokers relapse within 1 year of initiation of a quit attempt, while 56% of those relapse within one month (Bancej et al., 2007), and even more discouraging, a recent report showed that two-thirds relapsed within only 7 days (Wong et al., 2011). Relapse begins with a single smoking episode (i.e. lapse) that reliably progresses to daily smoking and often pre-cessation levels (Brandon, Tiffany, Obremski & Baker, 1990; Kenford et al., 1994). This process typically occurs very quickly, and traditional in-clinic treatments may fail to intervene and interrupt this progression from lapse to relapse. Interventions targeting this critical period are challenging to deliver, and

must be informed by careful prospective observation. Despite the public health relevance and implications of studying smoking in adolescents, very little is known about the natural history of a quit attempt and relapse in this group (Mermelstein, 2003). Studies with adolescent smokers frequently struggle with poor retention rates, which has led to inadequate sample sizes, underpowered outcomes, and largely ineffective results (Backinger et al., 2003; Skara & Sussman, 2003; Sussman, 2002). There is a clear need to aggressively focus research efforts on adolescent smokers in order to provide maximally effective smoking cessation interventions. Technology integration into smoking cessation research and treatment may provide innovative solutions to improve study design, retention, and outcomes.

THE REMOTE MONITORING OF SMOKING

Remotely monitoring health behavior and outcomes is an emerging area within the mHealth field, and is particularly important for adolescents. Adolescent smokers are an underserved, understudied population at high-risk for progression to more severe nicotine dependence and resulting health problems. Encouragingly, this is a population ideally suited for technology integration, as adolescents and young adults (12-29) show greater technology utilization compared to those over the age of 30, with mobile phones being the primary source of communication for the majority of adolescents in the US (Lenhert, Ling, Campbell & Purcell, 2010; Zickuhr, 2011). They are more likely to engage in and be early adopters of technology and more quickly acquire the skills necessary to use these resources. Also, technology integration may minimize clinic visits, adding to participant autonomy, which has been suggested to be paramount in retaining adolescents in smoking cessation trials (Kealey et al., 2007). Remote monitoring tools integrated into clinical trials hold the possibility for increased retention, reduced burden on participants, and higher-quality, more ecologically valid data sets.

Ecological Momentary Assessment

One system that has been at the forefront of the remote monitoring of smoking and relapse in adults is ecological momentary assessment (EMA; Shiffman, 2005, Shiffman, Ferguson, Gwaltney & 2006; Shiffman, Stone & Hufford, 2008). EMA collects real-time measures of dynamic processes contributing to smoking relapse during periods of abstinence (i.e. affect, contextual and situational variables, craving, and withdrawal) multiple times per day in the participant's natural environment, thus avoiding recall bias. Assessments can be randomly prompted (within certain parameters) and also may be participant-initiated. For example, by logging each cigarette immediately after smoking, participants are able to more accurately report on the conditions surrounding that particular cigarette since the recall period is short. This is important during a quit attempt, in which the first occasion of smoking (lapse) marks a critical point in the relapse process. Substantial work on relapse to smoking has been conducted in adult populations using EMA techniques through handheld devices (Shiffman, 2005; Shiffman et al., 2006; Shiffman et al., 2008) and implemented on cell phones using short message service (SMS) text messages and responses multiple times per day (Berkman, Ikle, DuHamel & Tinkelman, 2011) but limited EMA work has been conducted with adolescent smokers. Thus far, EMA studies with young smokers have demonstrated the role

of craving and negative affect (Gwaltney, Bartolomei, Colby & Kahler, 2008; Van Zundert, Ferguson, Shiffman & Engels, 2012), nicotine withdrawal (Van Zundert, Boogerd, Vermulst & Engels, 2009) decreases in self-efficacy (Van Zundert, Ferguson, Shiffman & Engels, 2010, and alcohol consumption (Van Zundert, Kuntsche, & Engels, 2012) in predicting a lapse and relapse after a brief period of abstinence. EMA data have stronger contextual validity and show promise in understanding the process and predictors of relapse in young smokers; however, they are still based solely on participant self-report, calling into question the accuracy of quit attempts, periods of abstinence, lapses, and subsequent relapse.

Consistent with these concerns, the validity of adolescent self-reports have been addressed in the literature. A myriad of reasons exist for why self-reports may be inaccurate and include, over- and under-reporting of tobacco use, as well as unintentional inaccuracies (Mermelstein et al., 2002). When biological verification of smoking has been compared to adolescent self-reports, concordance has been low (Kandel et al., 2006; Malcon et al., 2008); though better agreement exists between biological measures and self-reported assessments of nicotine dependence (Carpenter, Baker, Gray & Upadhyaya, 2010). EMA methods using real-time, momentary data collection circumvent issues of forgetting, but are still subject to altered accuracy and apathy towards reporting. An example of this was found in an EMA feasibility study, where Gwaltney et al. (2008) showed decreases in real-time cigarette entries throughout the monitoring period in adolescent smokers, but it is unknown whether this decrease reflects a true reduction in cigarettes per day or rather a decrease in reporting each cigarette. Reduced responding is particularly problematic since the system relies on certain participant-initiated events to prompt assessments. Given the concerns of self-report accuracy in adolescents, smoking cessation research and treatment would greatly benefit from comprehensive monitoring systems that integrate biochemical verification of smoking with self-reports to collect the most accurate, real-time assessments of the relapse process.

Biochemical Verification of Smoking Status

The two most common method for monitoring recent smoking via biochemical markers are the detection of the nicotine metabolite, cotinine, in saliva or urine samples, and the measurement of carbon monoxide (CO) in the breath. Breath CO is an accurate and non-invasive biological test to assess recent smoking. CO typically degrades quickly (half life 2-8 hours, depending on activity levels; SRNT, 2002), making frequent collection of samples preferred for accurate estimates of smoking. This frequency is unrealistic and burdensome for study participants and staff, and studies have explored innovative remote monitoring solutions to obtain biochemical verification of smoking, mainly with adults. These studies have provided participants with CO monitors (and webcams, if necessary) so they may record themselves leaving a breath CO sample, display the CO value on the video, and then upload the video clip to a secure server via an internet connection (Dallery, Glenn & Raiff, 2007). This system has been used successfully to deliver incentives contingent on abstinence from smoking (Dallery & Glenn, 2005; Dallery et al., 2007; see Dallery & Raiff, 2011 for a review), with very high sample submission rates (97.5% for 2 samples/day for 4 weeks; Dallery et al., 2007). This system has also been extended to use with rural smokers (Stoops et al., 2009), and in a pilot trial with adolescent smokers (Reynolds et al., 2008). The remote monitoring of breath CO reduces considerable burden, but participants must be

near a computer in order to leave a breath sample, thus diminishing the mobility of this system. Also, CO monitors that provide exact values in parts per million (rather than ranges of values) are expensive and cost-prohibitive for a large-scale, completely remote study intervention. Many large-scale and geographically diverse studies have been unable to verify abstinence with biochemical verification due to the limitations inherent to study design (i.e. contact with participants through mail, telephone, and Internet exclusively). Advances in mHealth that improve methods for monitoring objective smoking status hold promise for collecting additional, biochemically-verified outcomes without sacrificing large sample sizes and reach of the intervention.

Monitoring Individual Puffs

The biochemical verification of smoking tends to be the gold-standard in research studies for verifying abstinence, but it also comes with limitations. For example, CO levels can be elevated in the presence of second-hand smoke and due to other combustible inhalants, and do not identify smokeless tobacco use (SRNT, 2002). Cotinine (COT) has a much longer half-life than CO (approximately 16 hours; SRNT, 2002), but does not distinguish recent from past smoking, and some metabolites are unable to differentiate nicotine obtained from non-smoking sources (e.g., nicotine replacement therapy, smokeless tobacco, etc). Furthermore, biochemical measures of smoking provide general summaries of abstinence or reductions in smoking, but do not capture individual smoking events. This means that low levels of smoking may not be recognized by biochemical measures (SRNT, 2002; Stevens & Munoz, 2004).

One solution to the limitations encountered with biochemical markers of smoking is to have a monitoring system that is able to detect individual puffs from a cigarette or smoking occasions. Several systems to remotely detect smoking are currently being explored by those in engineering and computer science in collaboration with smoking cessation researchers, and thus far, have only been used with adult smokers. *Respirace*® is a device that measures chest expansion during smoking episodes (St. Charles, Krautter & Mariner, 2009). This system has been used in laboratory settings to monitor post-puff breathing patterns, but requires manual recording when the participant begins the puff episode. A second system, *mPuff*, also measures respiration patterns through chest expansion, but can be worn in the field and directly transmits information to a mobile device (Ali et al., 2012). Also, work is being conducted with inertial sensors that interface with mobile devices and make use of an algorithm that may be trained to detect certain patterns of movement of the arm and wrist; specifically, those that occur during smoking episodes (Varkey, Pompili & Walls, 2012).

While monitoring systems using EMA and biochemical verification submission require more effort on the part of the participant, sensing technology provides an unobtrusive system that may monitor continuously with little effort on the part of the participant, aside from the effort involved in wearing sensing devices. Sensing systems may not be realistic for long-term use, but could be of great importance initially during a quit attempt, when relapse tends to occur very quickly. A remote monitoring system capable of detecting individual puffs in the natural environment would have the ability to intervene at that very moment to prevent further smoking and disrupt the trajectory to relapse.

Mobile-delivered Interventions

The remote monitoring of smoking, to this point, has generally been focused on developing tools to accurately capture the process of relapse to inform effective and tailored treatment interventions to be delivered remotely. However, a number of studies are already implementing interventions delivered through mobile devices. The ubiquity of mobile phones throughout the world has led to the development of interventions based on SMS text messages or applications (apps) for mobile platforms. In the US alone, 95% of those 18-34 years old have mobile phones (Zickuhr, 2011), while 75% of teenagers from 12-17 years old own mobile phones (Lenhert et al., 2010).

One area of intervention delivery has grown out of EMA methods (ecological momentary intervention, EMI). These interventions occur in the participant's natural environment, where they are likely to be more efficacious, and are momentary, presumably when participants are in need of support. Heron and Smyth (2010) conducted a review of the EMI literature, with one section dedicated to smoking cessation. Results showed that four of the eight reviewed studies had adequate control conditions and of those, greater self-reported abstinence was found at the end of treatment for EMIs. The authors note, however, that many outcomes are based in self-report, and biochemical verification could provide added reliability.

A recent Cochrane review suggested that SMS-text message interventions for smoking have generally favorable outcomes for long-term cessation, however, results were variable across the limited number of studies reviewed (Whittaker et al., 2012). This updated review was more optimistic than a previous review from this same group (Whittaker et al., 2009), which found no effect of mobile-based interventions for smoking cessation. Also, Kaplan and Stone (2013) reviewed several health-related areas using mHealth methods and specifically for smoking cessation, they found some evidence of efficacy, though randomized controlled trials generally failed to showed effects of interventions on cessation. Also of concern was a review of smoking cessation mobile apps. Abrams and colleagues (2011) conducted a content analysis of smoking cessation apps available through the iTunes store up until June of 2009. Forty-seven apps were identified and analyzed, and showed low levels of adherence to evidence-based clinical practice guidelines (Fiore et al., 2008), and scant linkage to sources such as pharmacotherapy, counseling, or quitlines.

The ubiquity of mobile phones holds great promise for the smoking cessation field; however, the technology requires iterative and thorough testing in target populations prior to its use in large clinical trials or in dissemination efforts. Though this review is meant to focus on adolescents, very few studies specifically target that population for controlled trials of new technology. For example, no randomized, controlled trials testing SMS text messages to promote smoking cessation have been conducted exclusively for adolescents and young adults; though one is currently ongoing (Haug et al., 2012). Rodgers et al. (2005) recruited participants as young as 15, but the average age of participant was 22, not specifically targeting an adolescent population.

Mobile Health in Other Health-related Areas with Adolescents

Though this review has focused on technology integration for monitoring smoking in adolescents (when applicable), there are several other areas of investigation using mHealth methods for health-related research in adolescents that are worth noting. The problems encountered in conducting research with adolescents tend to span across fields of health-related study. Several specialties in health-related research and treatment for pediatric populations struggle with high treatment attrition, which leads to difficulty in analyzing and interpreting treatment effects (Bender, Ikle, DuHamel & Tinkelman, 1997; Jensen, Aylward & Steele, 2012; Karlson & Rapoff, 2009; Marcellus, 2004). Of great importance in these systems is the objective, remote monitoring of behavior or outcomes, combined with features of an intervention that include a comprehensive system of data tracking, motivational enhancement, education, use of peer groups or social networks, etc; which several investigators have started to explore. Systems are being developed and implemented to monitor physical activity in ethnic minority adolescents with the use of wireless accelerometers and heart rate monitors that interface directly with a mobile phone (Emken et al., 2012). Feasibility work has been conducted to remotely monitor glucose testing in adolescents with Type I diabetes through providing contingent incentives for recording glucose tests and values on a webcam, which is then uploaded to secure server (Mittiv⁸; Raiff & Dallery, 2010) and with an iPhone app that utilized reminders for blood glucose monitoring, social media communication, contingent incentives for monitoring (not specific to glucose values), and a blue-tooth enabled glucose monitor that transmitted data directly to the mobile app (Cafazzo et al., 2012). These few examples of technology integration into health-related research and treatment delivery in adolescents illustrates the infancy of this field and the thoughtful and iterative steps that are required in developing systems that adolescents will engage with and will also be effective in improving patient behavior and outcomes.

Limitations to Remote Monitoring

There are several limitations and considerations to the remote monitoring of smoking. Devices may be large and bulky during early iterations of feasibility testing, which may be burdensome for participants to keep with them at all times. Especially in the case of adolescent participants, they may not be able to carry devices (mobile or otherwise) during school hours, and special permission to use devices may draw unwanted attention. Appropriate first steps involve acceptability testing through focus groups and in small field studies to troubleshoot issues and assess the burden placed on participants. Acceptability at early stages will reveal what is reasonable to ask of participants, which can be extended to future protocols, even as devices become more compact, with longer battery life, and more computing power.

Though technology development is moving at an expedited pace, its integration into research and treatment is not always done with careful consideration for evidence- and theory-based science, and collaborations between multidisciplinary teams still remain rare and difficult to initiate and maintain. A review of weight loss applications on iTunes (Breton, Fuemmeler & Abroms, 2011) and smoking cessation apps (Abroms et al., 2011)

revealed that the content of these widely available apps generally did not conform to evidence-based information. Reviews of this sort stress the importance of investing effort initially in the development of these systems so they are consistent with evidence-based practices prior to large scale implementation. In fact, Czajkowski (2011) suggested that developing behavioral interventions should mimic procedures used to develop new pharmaceuticals.

While several other limitations to mHealth exist including, privacy and confidentiality issues, the analysis issues that accompany such large sets of data, the disparate pace of randomized controlled trials compared to technology development and penetration; the major challenge to researchers incorporating these techniques is to demonstrate that these methods go above and beyond what is possible through traditional methods. For smoking research, self-report has been the primary means of data collection for years. The use of mobile technology for monitoring smoking must demonstrate clear scientific and economic advantage to traditional methods. Studies in mHealth should consider direct comparisons between mobile technology with traditional methods to demonstrate and quantify these potential advantages. Researchers should also collaborate with health economists in order to conduct thorough cost-effectiveness studies to justify the use of potentially expensive equipment in research efforts. In the case of smoking cessation, CO monitors are expensive (ranging from \$600-1200 US) and providing a monitor to each participant in a study could be cost prohibitive. This justification could be made though if providing those devices leads to more effective and reliable methods and interventions to achieve long-term abstinence and healthcare cost savings. This rationale could be particularly powerful in adolescents if savings are calculated for the remainder of their lives should they stay a non-smoker.

Future Research

Adolescent smokers represent an understudied population who are in great need of effective smoking cessation interventions. Researchers struggle with recruitment and retention in treatment trials, minimizing the impact of the findings, and clinicians struggle with few effective recommendations to make to their patients. Smoking research in adolescents would greatly benefit from monitoring systems that do not rely primarily on self-report in order to collect the most accurate assessments of the relapse process. Studies utilizing remote monitoring sources would alleviate a great deal of burden placed on participants, parents/guardians, and research staff, while also improving the accuracy of data and outcomes. Traditional in-clinic smoking cessation interventions require visits one to two times per week, and typically fail to observe critical events in real-time, such as a lapse and the subsequent progression to relapse. By remotely monitoring smoking status during a quit attempt, lapses could be caught quickly and interventions could be delivered immediately and remotely to minimize the chances of progression to full relapse.

While remote monitoring technology is appealing for adolescent smokers, it is unrealistic to expect long-term compliance with these sometimes burdensome and bulky devices or sensors that must be worn throughout the day. Wong and colleagues (2011) recommended intensive monitoring during the first week of abstinence in youth smokers in order to recognize withdrawal symptoms and identify relapse so that interventions may then be

administered to enhance or re-instate motivation if a lapse or relapse has occurred. Short periods of intensive monitoring are more realistic, but the time frame must be empirically demonstrated as adequate to promote long-term abstinence.

Though internet-delivered interventions were not discussed here, they also offer a source of additional participant contact, data collection, educational material, and many mobile interventions already include internet components. The majority of US adults (78%) and teenagers (95%) are online (Zickuhr & Smith, 2012), and this technology source should not be overlooked as part of a comprehensive monitoring system.

The eventual goals of remotely monitoring smoking is to provide an unobtrusive or minimally invasive monitoring system to identify the antecedents of lapse in smokers trying to quit so that maximally effective, just-in-time interventions may be delivered at critical moments to promote long-term abstinence. These goals will require careful, iterative testing and the use of potentially expensive devices, however, the cost of these techniques should be considered in terms of the inevitable costs that will be incurred if smoking during adolescence progresses and persists throughout their lifetime.

Acknowledgments

This work was supported by NIDA Awards U01DA031779 and U10DA013727.

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