Annual Review of Cybertherapy and Telemedicine
Volume 4 Year 2006 ISSN: 1554-8716

Virtual Healing: Designing Reality

Editors:
Brenda K. Wiederhold, PhD, MBA, BCIA
Stéphane Bouchard, PhD
Giuseppe Riva, PhD, MS, MA

Interactive Media Institute
Physiological and Momentary Assessment for Identifying Tobacco Use Patterns

P. J. Jordan, Ph.D., L. W. Jerome, Ph.D., N. Faraj R.D., M.S.

Pacific Telehealth & Technology Hui
Honolulu, HI

Abstract: Cigarette smoking is the leading cause of morbidity and mortality in the United States. Approximately 70% of smokers report that they want to quit but only about 4% of smokers who try to quit smoking each year succeed. Nicotine is a highly addictive, psychoactive drug that induces physiologic and psychological effects that clearly reinforce the continued use of tobacco products (Smith, 2003). Research with sensor technologies supports the utility of biosensors for the detection and prediction of arousal associated patterns of tobacco use. Sensors have the ability to capture data that can be used to create algorithms for the identification and prediction of arousal patterns associated with cravings and addiction. If we can identify physiologic patterns associated with craving, it may be possible to intervene prior to the onset of an addiction-behavior spiral. The primary objective of this ongoing three-phase study is to detect the physiological antecedents that prompt smokers to use tobacco through the analysis of biometric and behavioral data. For Phase 1, nine smokers completed baseline questionnaires about smoking history, self-efficacy to quit smoking, decisional balance, and readiness to change. Participants wore non-invasive armband sensors continuously for seven days at baseline and for four days at three-month follow-up. Participants pressed an “event button” on the armband each time they lit a cigarette. This article will present the methodology and analyses that are being used for the development and testing of predictive algorithms, and will discuss implications and future applications of these findings. Biometric and psychological data are currently being analyzed. The goal of data analysis during Phase 2 is to generate statistical algorithms, based on individual baseline patterns of craving and tobacco use. The goal of Phase 3 is to then use the follow-up data to test the predictive validity and specificity of the algorithms created in Phase 2. This research lays a foundation for developing innovative treatment approaches by integrating contemporary advances in technology with emergent findings related to the biological substrates and behavioral mechanisms of cravings and addictions. The information gained from this pilot research is a requisite step for the development of innovative behavioral health interventions that will endow consumers with greater control over maintaining their health. New interventions are envisioned that will be tailored to individual biometrics and daily routines, delivered at optimal moments for effective intervention.

INTRODUCTION

Cigarette smoking is the leading cause of preventable disease, disability, and death in the United States, contributing to the deaths of more than 430,000 people each year (Centers for Disease Control and Prevention [CDC], 2005b). Currently, approximately 21% of U.S. adults are smokers (CDC, 2005b). Smoking is associated with a broad range of serious illnesses, chronic disease, reproductive effects, and increased risk for certain types of cancers. Smoking cigarettes causes over 85% of lung cancers and 30% of all cancer deaths (CDC, 2005b). Approximately 70% of all smokers report that they would like to quit (CDC, 2002).

While a number of evidence-based pharmacological and behavioral interventions have proven to be effective in smoking cessation, 70-80% of smokers relapse after a single quit attempt and require several serious attempts before becoming smoke free (Schacter, 1992; Schwartz, 1987).

Emerging technologies offer new opportunities for delivering behavioral interventions (Walters, Wright, & Shegog, 2006). Electronic modes of delivery are well suited for tailoring interventions to the individual, a strategy that has proved to be more successful than non-tailored or no interventions (Strecher, Wang, Derry, Wil-
Tailored behavioral interventions have typically been based on self-report assessments, the results of which are matched to a specific characteristic of the individual (e.g., gender, stage of change, nicotine dependence), or a combination of two or more psychosocial variables (e.g., self-efficacy, perceived barriers, attitude, social support, etc.); however, these types of expert systems are based on static variables and delivered at a time not usually controlled by the researcher. New technologies offer unique opportunities for the translational scientist to advance treatment programs by building on contemporary understandings of the biological substrates and behavioral mechanisms of nicotine and tobacco addiction.

Recent investigations using biosensors suggest that the physiologic arousal associated with specific behavioral events can be accurately detected and predicted (Adam, 2005; Doser et al., 2003; Lang, 1995). Sensor technologies for human behavior have been used for this purpose, to determine whole body and specific behavioral measurement related to sports, entertainment, and medical care (Kanasugi, 2005). Furthermore, autonomous agents are currently being utilized to create adaptive responses to dynamic environments. Researchers at the MIT Media Lab are developing a wearable system with sensors that can continuously monitor the user's vital signs, motor activity, social interactions, sleep patterns, and other health indicators (Pentland, 2004). These wearable systems amass objective data to improve diagnoses and provide early warning of an impending health crisis.

Cravings are critical factors associated with smoking behaviors and relapse (Kelly, Barrett, Pihl, & Dagher, 2004). Most smokers experience cravings and withdrawal symptoms within a few hours of abstaining from nicotine (Smith, 2003). Even a partially abstinent smoker can be regarded as being in a chronic state of withdrawal (U.S. Department of Health, Education and Welfare, 1979). Cravings for cigarettes and other addictive substances are both physiologic and behavioral events that lend themselves to measurement and pattern detection. Decreases in heart rate and diastolic blood pressure, as well as a decrease in metabolic changes, are observed as early as six hours after cessation (U.S. Department of Health, Education and Welfare, 1979). These physiologic aspects associated with craving are predictable and measurable.

While physiologic patterns associated with cravings have not been a previous research focus, the relationship between tobacco smoking and stress has long been an area of interest (Smith, 2003). Kecklund and Åkerstedt (2004) concluded that there are many well-established physiological markers for the measurement of stress. This research provides good evidence for the arousal patterns that appear related to cravings. Individual stress responses are quite consistent, even when the stressor differs (Levine, 1986); however, individual variations in baseline levels and reactivity patterns are large, making it difficult to establish normative values or cut-offs. Fortunately, individual variance can be mitigated by strategies that measure several parameters simultaneously and examine the fluctuations over time (Kecklund & Åkerstedt, 2004). It is not the overall level of a single physiological marker that discriminates between low and high stress situations; rather, it is the profiles over time that reflect the differences. This is the basis upon which the current research builds.

Participants in the current study wore non-invasive sensors to collect continuous biometric data including motion, heat flux, skin temperature, and galvanic skin response. Each time participants lit up a cigarette, they pressed an “event stamp” that recorded their tobacco use as a specific behavioral event in the raw physiologic data. It is our hypothesis that biometric data can be used to create statistical algorithms to identify and predict the arousal patterns associated with craving and/or tobacco use behavior. To facilitate the predictive modeling, algorithms utilizing both deep knowledge and surface knowledge (Velicer & Prochaska, 1999) are being used in order to create individually tailored responses that will adapt based on an incoming stream of physiological data. This research seeks to develop a conceptual model that, in our long-range vision, establishes the foundation for developing new approaches to smoking cessation interventions, which will be tailored to individual physiological and psychological patterns of behavior.
The technical framework on which the project is based is artificial intelligence research that has matured to the point where it can be applied to commercially available products and informed by theoretically sound therapies, such as cognitive behavioral therapy, social learning theory, and the transtheoretical model. Through these methodologies, we seek to develop tailored interventions that will adapt according to individual styles, patterns, and readiness for change.

There are three phases to this study. Phase 1 consisted of continuous biometric data collection from nine cigarette smokers. Baseline data were collected via non-invasive biosensor armbands that participants wore 24 hours a day for a period of seven days. Three-month follow-up data were collected for four days’ duration. We are currently completing Phase 2 of the study, which is focused on the exploration of the Phase 1 data to identify physiological arousal patterns that are associated with smoking. This data will be used to develop statistical algorithms for the accurate prediction of individual patterns of tobacco use and smoking behavior. We have also commenced with Phase 3 of the project wherein data is being collected from eight of the nine Phase 1 smokers. The aim of Phase 3 of the study is to verify the strength and predictive ability of the algorithms created in Phase 2. Given the ongoing nature of this research and data analysis, this paper will address the theoretical basis for the study, the methods, and the anticipated findings and implications of this project.

METHOD

Participants

Human subjects approvals were obtained by the University of Hawai‘i’s Institutional Review Board and the U.S. Army and Materiel Command’s HSSRB. Recruitment was conducted primarily at the university campus between October 2005 and February 2006 using flyers, handbills, public service announcements, e-mail and classroom presentations. Inclusion criteria for the study required participants to be current smokers between the ages of 18 and 54, English-speaking, in good health, and demonstrate the ability to read, understand, and complete all self-report questionnaires. Prospective participants were considered ineligible if they were undergoing Nicotine Replacement Therapy for smoking cessation, reported any smoking-related health conditions, and/or required prescription medication that may affect the normative data collected by the biosensor (e.g., asthma, hypertension, low cardiorespiratory fitness, etc.). All participants were required to wear an armband biosensor for 24-hours per day for a one-week period. Informed consent was obtained from all participants following a 30-minute orientation to the study and the equipment involved, and prior to their completion of baseline questionnaires. A total of 11 participants were recruited to the baseline Phase 1 portion of this study; however two individuals were unable to complete the seven-day baseline citing personal reasons (n=9). All participants were contacted to participate in a three-month follow-up for an additional four-day trial. Eight of the 9 participants agreed to participate in the follow-up phase, which was completed in May 2006. The ninth participant was no longer eligible to participate, having quit smoking approximately one week after Phase 1 was complete.

Measures

Self-report questionnaires

Immediately following informed consent procedures and orientation, participants completed the following baseline measures.

Smoking History and Behavior (BCC-LM): The Behavior Change Consortium’s (BCC) Tobacco Dependence Workgroup (TDW) recommends a combination of validated smoking behavior questionnaires (Williams, McGregor, Borrelli, Jordan, & Strecher, 2005). The BCC-LM includes the Fagerstrom Tolerance Questionnaire (Fagerstrom & Schneider, 1989), a stage of change assessment (DiClemente et al., 1991), and single-item assessments of seven-day point prevalence, confidence to quit, motivation to quit, habit, and smoking environment.

Situational Self-Efficacy (Temptations): This nine-item measure determines each participant’s situational temptation to smoke (Velicer, DiClemente, Rossi, & Prochaska, 1990). The measures support three-item subscales: 1) positive affect/social situations; 2) negative affect; and 3) habit/craving. Respondents were asked to rate their own temptation to smoke on
A five-point Likert scale, ranging from “not at all tempted” (1) to “extremely tempted” (5). Lower self-efficacy scores have been shown to be a predictor of increased smoking behavior, increased risk for relapse (Yates & Thain, 1985), and perceived severity of addiction (Rothman, 2000). Low self-efficacy is also associated with poor coping response to stress (Gerin, Litt, Deich, & Pickering, 1996).

**Pros and Cons (short form):** This six-item measure will be used to assess changes in decisional balance (Velicer, DiClemente, Prochaska, & Brandenburg, 1985). Respondents were asked to rate the importance of each item in their decision to smoke on a five-point Likert scale, ranging from “not important at all” (1) to “extremely important” (5). Pros and cons are associated with smoking cessation (Bane, Ruggiero, Dryfoos, & Rossi, 1999). Furthermore, the magnitude of shifts in decisional balance is indicative of an individual’s readiness to change behavior (Prochaska, 1994).

**Physiological Measures**

*BodyMedia SenseWear® Pro, armband:* It has already been established that cigarette smoking and the arousal associated with withdrawal generates a number of physiological and metabolic changes, affecting heart rate, skin temperature, and skin conductance. Many of these same data channels were collected by the armband sensor: heat flux—the rate of heat exchanged between the wearer’s arm and the outside environment; skin temperature—temperature of the skin under the armband; reflective of the body’s core temperature, although it is several degrees cooler; ambient temperature—the air temperature immediately around the arm; galvanic skin conductance—has been found to correlate positively with novel stimuli, intensity, and/or emotional content, and may also show increased levels during stress (Andreassi, 2000; Fichera & Andreassi, 1998); movement—longitudinal and transverse accelerometers track forward and lateral movement.

**Procedure**

During the first phase of the study, participants wore the armband continuously for seven days as a means of collecting baseline data. Participants were instructed to press an “event button” on the armband each time they lit up a cigarette. The event button recorded a timestamp (or “annotation”) on the raw data, so smoking could be correlated with a physiological antecedent. The researchers made no attempt to control extraneous variables and the participants’ were instructed to carry on with their normal daily routines.

**Data Analysis Plan**

Biometric data collected by the armbands were downloaded directly using InnerView™ Research Software v4.0, developed by BodyMedia specifically for the device. Data were exported into Microsoft® Excel and MATLAB for analysis. Data from the self-report questionnaires were input, managed, and analyzed with SPSS 14.0.

Gaussian smoothing filters have been applied to the physiologic data as a means of partitioning five-minute averages for sequential data points. This form of data reduction will provide a more manageable data set. Data analysis will include the statistical analysis of physiological (sensor) and self-report data collected from participants to detect associations between tobacco use and variance in the physiological data.

**Hierarchical Linear Regression**

A collection of bivariate and multivariate analyses will be used to create algorithms from the best linear combination of all physiological and psychological variables. Specifically, the algorithms will be developed from the physiological data collected by the participants’ armband data, participants’ smoking events, and self-report questionnaire data.

A series of multivariate regression analyses will be utilized in the initial steps of algorithm development. Algorithms created from the derived functions will utilize a split-half subset of the data. These will be tested against the balance of the collected observations. In the next stage of analysis, a search algorithm will be run in an attempt to identify a subset of data that produces accurate descriptors. After a subset of data has been identified to be an accurate predictor, cross-validation will be used to randomly divide the data in an attempt to validate the algorithm (Reunener, 2003). Hierarchical linear regression will be used to explore combinations of both physiologic and psychological constructs in order to reduce the
variable set to a minimum set of predictors (Raudenbush & Bryk, 2002).

**Algorithm Development**

Response algorithms will be designed utilizing an autonomous agent framework. This algorithm architecture was selected because of its ability to adapt responses to subsequent data. Sequential Forward Floating Selection (SFFS) will be applied to determine best fit for the constraints imposed by the data collection method and sample size of the study. SFFS in combination with Fisher Projections also result in robust predictive models having an accuracy rate of as much as 81% (Nasoz, Alvareze, Lisetti, & Finkelstein, 2003). Back propagation neural networks have also demonstrated an ability to predict behaviors from large sets of data that don’t easily correlate to results.

Initially, normative data will be given greater weight in the prediction of smoking events. As supplementary individualized data is processed, individualized predictive models will be derived for each subject. The modeling algorithms will slowly shift reliance from normative data to individualized tobacco use indicators over time. After a substantial accumulation of individualized data is collected to accurately predict patterns associated with tobacco use, the reliance on normative data as a predictive tool will be gradually eliminated from the calculations. The strength and predictive ability of these algorithms will be examined in a later phase of the study.

**RESULTS**

**Descriptives**

Descriptive statistics were tabulated for the sample (n=9). Participants were predominantly male (63.6%), with a mean age of 32.9 (SD=10.3), college educated (mean years of education=15.3, SD=2.8), unmarried (55.6%), and in very good health (55.6%). Most participants identified their ethnicity as White (77.8%), Samoan (11.1%), or Chinese (11.1%), with 22.2% claiming Hispanic origins.

**Smoking History**

Overall participants began smoking in adolescence (mean age=16.4, SD=3.6), have smoked an average of 15.3 years (SD=11.9), and smoke an average of 25.9 cigarettes per day (SD=26.8). Participants reported little readiness to change, and self-selected into either the pre-contemplation (77.8%) or contemplation (22.2%) stage of change for smoking cessation. Participants in this study rated a moderate to high level of nicotine dependence, with a mean nicotine dependence score of 4.6 at baseline (SD=2.5; range=0-7). According to the Fagerstrom Nicotine Tolerance Questionnaire (FNTQ; Fagerstrom & Schneider, 1989), individuals who score between 7-10 demonstrate a high level of addiction (n=1), scores between 4-6 indicate a medium level of addiction (n=5), and scores below 4 correspond to low levels of addiction (n=2).

**Baseline and Follow-up Comparisons**

Phase 1 participants wore the armband over a seven-day period for an average of 9,314 minutes (SD=1558.1; range=6,808 - 12,526). During Phase 1, participants smoked an average of 108.78 cigarettes in total (SD=92.2 range=36-330), an average of 0.7 cigarettes per hour (SD=.6; range=0.23-2.03). At baseline, most participants reported being in the pre-contemplation stage for smoking cessation (77.8%; n=9). Baseline participants also reported a mean decisional balance (cons of quitting minus pros of quitting) value of -3.0 (SD=13.7).

Participants in the follow-up phase wore the armband for a period of approximately four days for an average of 4,675.4 minutes (SD=1,628.0; range=1,765-6,737). During the follow-up phase, participants smoked an average of 63.3 cigarettes in total (SD=59.6; range=9-180), an average of 0.7 cigarettes per hour (SD=.6; range=0.15-1.88). Follow-up participants had a mean FNTQ score of 5.9 (SD=2.8; range=2-10). These participants also reported a slight shift in stage of change distribution with 62.5% (n=6) at pre-contemplation, and 25% (n=2) at preparation. Average decisional balance scores at follow-up were positively skewed at 4.38 (SD=11.5).

**DISCUSSION**

Nicotine is a highly addictive, psychoactive drug that induces physiologic effects to reinforce the continued use of tobacco (Smith, 2003). Distinct patterns of withdrawal symptomatology have
been specified in the DSM-IV (American Psychiatric Association, 1994), and include depressed mood, insomnia, irritability, anxiety, difficulty concentrating, restlessness, and increased appetite. Definitive physiological changes are found to occur with cigarette deprivation, including decreases in heart rate, decreases in cortical arousal associated with drowsiness and decreased vigilance, hypersensitive visual stimuli, reduction in auditory evoked response, decreases in blood pressure and respiratory rate, and increases in skin temperature (CDC, 1988). These physiologic parameters are observable and measurable across time and therefore predictable at an individual level.

In recent years, the capacity of sensor technology has increased and portability has improved. Non-invasive, wearable wireless sensors offer new opportunities for research and intervention for a broad range of psychophysiological research. Specifically, research using sensor technologies supports their utility for the detection and prediction of arousal associated with addictions. Because of high relapse rates, researchers now characterize tobacco dependence as a chronic condition that requires repeated intervention (Paul & Lucas, 2005). Autonomous agents have been successfully used to create adaptive responses to dynamic environments. This means that individually tailored, early intervention methodologies are possible to assist in treating addiction in more timely and meaningful ways. Interventions will be useful for treating addictions of all kinds, including those who are resistant to change, those already in treatment, and those who need help preventing relapse.

Sensors have the ability to dynamically capture physiological data. The current research seeks to demonstrate the capability of developing statistical algorithms to accurately identify and predict arousal patterns associated with individual cravings and/or tobacco use behaviors. The algorithms are being developed from physiological data collected by wearable sensors with timestamps and subjective data provided by participants. The algorithms developed in Phase 2 of the current study will be used with participants’ follow-up data in Phase 3 as part of a beta testing trial to assess the predictive validity and reliability of the algorithms with a view toward determining the optimal time-frame for delivery of a cessation or relapse prevention message.

As data from this project is analyzed, a larger project is envisioned that will expand on the pilot project in three ways: the sample size will be increased; a more robust research design has been constructed; and the project will be augmented with the addition of a controlled laboratory condition. The project will be carried out in order to provide definitive evidence that patterns of physiological arousal associated with tobacco craving can be identified in smokers through statistical algorithms; to differentiate between psychological craving and physiological arousal in smokers; and, to identify robust algorithms that can be used for intervening in tobacco use behaviors.

It is possible that each individual’s cravings demonstrate a unique physiologic pattern that is identifiable by immediate changes in one physiologic channel (e.g., heart rate, skin temperature). It is also possible that the gateway channel may be different for each individual. This program of research seeks to understand these patterns and develop a conceptual model for developing new approaches to smoking interventions. Tailored and portable intervention applications are envisioned for a variety of addictions. Identifying individual patterns of craving and tobacco use may provide a window for the earliest possible intervention, before a spiral of behavior begins. Interventions that are designed to be delivered ‘just-in-time,’ offer critical opportunities for optimal effectiveness.

REFERENCES


**CONTACT**

Patricia J. Jordan, Ph.D.
Research Methodologist
Pacific Telehealth and Technology Hui
459 Patterson Road, 4th Floor, E-wing
Honolulu, HI, 96819-1522
E-mail: pjjordan@hawaii.edu