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SPECIAL ISSUE ON ADDICTIONS

Technology-Based Contingency Management in the Treatment of Substance-Use Disorders

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Abstract
Contingency management is one of the most efficacious interventions to promote drug abstinence. Contingency management has traditionally been delivered in person so that clinicians could confirm drug abstinence and provide access to additional therapeutic services. Now, new technologies not only permit remote confirmation of abstinence, but also remote delivery of incentives. We discuss several technology-based tools to assess substance use, and new ways to deliver contingency management to promote tobacco, alcohol, and cannabis abstinence. These new tools have the potential to dramatically increase access while maintaining high levels of treatment fidelity. Technology-based methods also allow arranging group contingencies that harness online communities, and they permit targeting multiple health-risk behaviors with a combination of sensor-based technologies. Overall, there are unprecedented opportunities to link technology with contingency management to promote drug abstinence.

Keywords Contingency management · Incentives · Substance-use disorders · Technology

Since the early 1970s, hundreds of experimental studies and randomized controlled trials (RCTs) have demonstrated the effectiveness and versatility of contingency management (CM) interventions (Davis et al., 2016; Higgins, Silverman, & Heil, 2008). Under CM interventions, monetary or prize-based reinforcers[1] are delivered contingent on objective evidence of drug abstinence. CM has been applied successfully to treat dependence to licit and illicit drugs in a variety of special and underserved populations (e.g., individuals with

[1]We will use the term "reinforcer" rather than "incentive" for historical accuracy in the context of the development of CM, and to highlight the rich conceptual and empirical foundations of how reinforcer properties may be tailored to improve treatment outcomes. We use the term in a nominal sense only; we cannot claim that the functional criteria for use of the term are satisfied for any given study or individual (Catania, 2012).

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serious mental illness, pregnant women), adults, and adolescents (Higgins et al., 2008). Several systematic reviews have concluded that CM is effective in the treatment of substance-use disorders (SUDs; Dutra et al., 2008; Lussier, Heil, Mongeon, Badger, & Higgins, 2006; Prendergast, Podus, Finney, Greenwell, & Roll, 2006), and that it may be more effective than other psychosocial interventions such as relapse prevention and cognitive-behavioral therapy (Dutra et al., 2008).

CM is the most rigorously tested and broadly successful application of behavior analytic principles in randomized controlled trials (RCTs; Dallery, Defulio, & Meredith, 2015). As such, CM is a behavior analysis success story. CM arose from basic laboratory research showing that drugs of abuse could serve as primary reinforcers in nonhuman animals, and that drug self-administration was sensitive to parametric variation in reinforcement such as immediacy, magnitude, and frequency (Bigelow & Silverman, 1999; Higgins, Heil, & Lussier, 2004; Silverman, 2004). These observations provided strong evidence that drug seeking is operant behavior. The early pioneers of CM also explicitly incorporated the finding that linking the absence of a problem behavior with contingent delivery of a reinforcer leads to dramatic reduction or elimination of problem behavior (Hunt & Azrin, 1973; Miller, 1975; Stitzer et al., 1977; Stitzer & Vandrey, 2008). The principle of reinforcement, in concert with empirically derived knowledge of how parameters of reinforcement affect behavior, catalyzed the conceptually systematic and effective behavioral technology manifested in CM (Baer, Wolf, & Risley, 1968).

One barrier to CM treatment is access. CM procedures such as drug monitoring and reinforcer delivery traditionally occurred in person, and therefore access was limited to those individuals proximate to a treatment center. Although in-person access has expanded considerably in recent years (e.g., Petry, Dephilippis, Rash, Drapkin, & McKay, 2014), innovations in digital and information technology may permit unprecedented access to some forms of CM treatment. Over the past 14 years, technology-based CM has been applied successfully to a range of problem health behavior such as cigarette smoking, alcohol misuse, physical inactivity, and medication nonadherence (Kurti et al., 2016; Kurti & Dallery, 2014). These behavioral patterns now represent the largest proportionate contributors to premature death, for the first time overtaking other contributors such as genetic predisposition, social circumstance, access to health care, or environmental exposures (Schroeder, 2007). It is remarkably, behavioral scientists can now remotely monitor almost all of these behavior patterns using technological tools such as accelerometers, electronic sensors, and biochemical detectors (Dallery, Kurti, & Erb, 2015; Marsch, Lord, & Dallery, 2014).

In this article, we trace the rise of internet-based applications in the area of cigarette smoking, and we highlight the use of technology to arrange group contingencies and deposit contracts to promote cessation. We also review recent mobile phone-based applications for cigarette smoking, alcohol use, and cannabis use. Finally, we discuss advances in digital and behavioral technology that may increase access and cost-effectiveness, and further optimize technology-based CM.

Internet-Based Contingency Management

Three features characterize technology-based CM, all of which entail remote methods using a computer or a mobile phone with internet connectivity: a monitoring procedure to detect drug use, a reinforcement delivery procedure, and a user-authentication procedure to verify the end-user's identity (Dallery, Kurti, & Erb, 2015). Although automation of these remote methods has advanced, in the early examples of technology-based CM only the monitoring system was automated. That is, the reinforcement and user-authentication procedures involved research staff viewing and verifying the end-users' identities and then sending statements of their earnings via email.

Dallery and Glenn (2005) developed the first technology-based CM intervention using laptop computers with internet connectivity. The target was cigarette smoking, which is the leading preventable cause of death and disease in the developed world. Several previous studies had already demonstrated that in-person CM could exert powerful control over smoking (Roll, Higgins, Steingard, & McGinley, 1998; Sigmon, Lamb, & Dallery, 2008; Stitzer, Rand, Bigelow, & Mead, 1986; Stitzer & Bigelow, 1983). In these studies, breath carbon monoxide (CO) served as the objective marker of smoking status. Breath CO can be obtained with a handheld monitor, and the procedure is noninvasive and produces immediate results. Breath CO, however, is cleared rapidly from the body, decreasing by 50% every 4–6 h. This leads to a challenge with breath CO: samples must be collected frequently to obtain a reliable index of smoking status (e.g., twice daily; Javors, Hatch, & Lamb, 2005).

Dallery and Glenn (2005) used web cameras to record the breath CO monitoring procedure twice per day, 7 days per week. Four participants experienced a brief baseline phase during which COs were monitored. The baseline phase varied in duration according to a concurrent multiple baseline design. Participants then experienced a 4-day shaping phase, during which gradual reductions in CO were reinforced with a $3.00 voucher, and then a 10-day abstinence induction phase during which abstinence (CO $\leq$ 4ppm) was reinforced. Based on evidence of abstinence, monetary vouchers (statements of earnings) were emailed to participants. Earnings could be redeemed for online goods and services. The value of the voucher started at $3.00 and increased by $0.25 for every consecutive negative CO. In addition, a bonus of $5.00 was delivered for every third consecutive negative sample, and the schedule returned to the original voucher value if the CO sample was missing or positive for smoking (Higgins et al., 1993; Roll et al., 1998). After the abstinence induction phase, during a 4-day thinning phase, participants could earn $5.00 for their fourth and eighth samples if they were negative. The other COs were simply collected; no contingency was imposed on these samples. This phase was included so that participants would not experience an immediate termination of earning contingent vouchers. Finally, the last 5 days were identical to the baseline condition (i.e., a return-to-baseline), with the exception that the duration of the condition was held constant across participants. Each participant could earn a maximum of $171.50 in voucher earnings if he or she was abstinent for the duration of the study. During baseline, 7% of the CO samples were negative, whereas 60% were negative during the abstinence induction phase.

Dallery and Glenn's (2005) findings were replicated in a second study that enrolled 20 heavy smokers (mean 25.5 cigs smoked/day, 20.4 years smoked; Dallery, Glenn, & Raiff, 2007). Over 97% of the 1,120 scheduled CO samples were collected. Less than 3% of CO samples were negative during baseline, and 66% were negative during the abstinence induction phase (negative was defined as CO $\leq$ 7ppm). In both studies, reversals to baseline CO levels in the return-to-baseline phase did not occur consistently. A third RCT study more clearly suggested CM efficacy: the median percentages of negative samples during the intervention in the control (noncontingent earnings; n = 38) and CM treatment (n = 39) groups were 25% and 66.7%, respectively (CO ≤ 4 ppm[2]; Dallery, Raiff, & Grabinski, 2013).

Special Populations

One promise of technology-based CM is that it can reach populations that have been traditionally hard-to-reach or underserved. This promise has been explored in two special populations: rural and adolescent smokers. Rural residents are considered a "special population" due to their lack of economic, health, and educational resources. Overall, rural communities have higher rates of chronic illness and disability and report poorer overall health than do residents of nonrural communities (Martin, 2013; Probst, Moore, Glover, & Samuels, 2004).

Stoops et al. (2009) conducted a RCT demonstrating the effectiveness of technology-based CM in smokers residing in rural Appalachia. During the 6-week intervention period, participants (n = 35) in the Abstinence Contingent (AC) group received monetary reinforcers contingent on recent smoking abstinence (i.e., CO ≤ 4 ppm). Participants (n = 33) in the Yoked Control (YC) group received monetary reinforcers based on their yoked partner's earning but independent of smoking status. The yoking procedure ensures equivalent voucher earnings in both groups, which eliminates differences in earnings as a confounding variable. Participants in the AC group were significantly more likely than the YC group to post negative CO samples on the study website (odds ratio = 4.6). This odds ratio translates to the AC group providing up to four times more abstinent samples than the YC group in weeks 2–6 of the intervention. Significant differences were observed between groups within the first 2 weeks of treatment and persisted through the 6-week intervention. These results demonstrate the powerful early onset of efficacy and the feasibility of technology-based CM in a rural population.

The study by Stoops et al. (2009) employed a CM software platform called Mōtiv8. Mōtiv8 automated both the CO monitoring system and the reinforcer delivery system. The Mōtiv8 system provided immediate feedback to participants about progress in the program. An earnings statement was automatically generated based on CO results, and a graph showing overall progress in the program was displayed on participants' home pages. Videos of the CO sampling procedure were transmitted via a secure, encrypted connection, and housed on a dedicated study server. Study personnel could access participant videos through Mōtiv8 to verify the validity of submitted breath-sample videos and to confirm program earnings.

Another hard-to-reach population is adolescent smokers. Smoking during adolescence is more likely to lead to nicotine addiction than starting at a later age, and nicotine addiction can occur within 1 month of smoking initiation (Karpinski, Timpe, & Lubsch, 2010). Reynolds, Dallery, Shroff, Patak, and Leraas (2008) used a reversal design in four adolescent smokers (14–17 years old). Three breath CO samples were

[2] In these initial studies, the cutpoint for a negative breath sample ranged from 4 to 6 ppm. The reason for this range is that available expert and empirical guidance regarding optimal cutpoints varied over the time at which each study commenced (e.g., Javors et al., 2005).

required daily, each separated by at least 5 hr but not by more than 8 hr Participants were paid in cash on a weekly basis for valid samples. The same conditions used in Dallery and Glenn (2005) were used (baseline, shaping, abstinence induction, thinking, return-to-baseline). Adherence to the program was high: 350 out of the total 360 CO samples were collected (97.2%). Participants continued to smoke during baseline, but all achieved prolonged periods of abstinence during the abstinence induction phase.

In contrast to the results of Reynolds et al. (2008), a recent RCT of a diverse sample of 127 adolescent smokers indicated poor adherence to the procedures (Harvanko et al., 2018). Only 37% of samples were obtained in the CM group, and 51% were obtained in the control group (in which incentives were based on CO submissions only). Perhaps in part due to low adherence, differences in smoking outcomes were minimal. Statistically significant differences in breath CO between groups only appeared during the thinning phase (9.9 ppm vs. 6.9 ppm in the CM vs. control group, respectively).

The difficulties in treatment access experienced by adolescents and rural populations separately may be compounded for adolescent, rural smokers. Reynolds et al. (2015) evaluated a technology-based CM program via Mōtiv8 with adolescent smokers recruited from rural Appalachia. Participants were assigned to either a CM condition (n = 31) or a control condition (n = 31) in which providing timely video recordings were reinforced with no requirement to reduce breath CO. Results revealed that participants in the CM condition reduced their breath CO levels significantly more so during treatment than participants in the control condition (statistically adjusted mean CO during the abstinence phase was 4.6 ppm in the CM group and 9.5 ppm control group). The study also revealed some challenges in treating this population with technology-based CM. First, adherence was lower than in previous studies: the median percentage of submitted program breath samples through Mōtiv8 was 46.03%. The reasons for low adherence in this study and the Harvanko et al. (2018) study are not clear. Similar reinforcer magnitudes and treatment durations were arranged as compared to other studies. It may be that the 3 per day sampling procedure was too burdensome in this population relative to a 2 per day sampling procedure. Second, broadband service was limited in the study catchment area, and some equipment had to be loaned to participants (e.g., laptop computers). As internet connectivity and mobile phone ownership continue to increase exponentially in rural areas, some of these remaining barriers to treatment may be mitigated.

Group Contingencies

Technology-based CM has been used to arrange group contingencies, where small groups of smokers must collectively achieve cessation goals to receive consequences (Dallery, Meredith, Jarvis, & Nuzzo, 2015; Meredith, Grabinski, & Dallery, 2011; Meredith & Dallery, 2013; see also Kirby, Kerwin, Carpenedo, Rosenwasser, & Gardner, 2008). Several types of group contingencies are possible. Under independent group contingencies, consequences are contingent on individual performance, but the contingencies are applied simultaneously to all members of a group. In contrast, under dependent and interdependent group contingencies, “the behavior of one or more group member determines the consequences received by at least one other group member” (Speltz, Shimamura, & McReynolds, 1982, p. 533). One advantage of dependent and interdependent group contingencies is that they may promote social support such as cooperation or abstinence-contingent praise (Gresham & Gresham, 1982; Williamson, Williamson, Watkins, & Hughes, 1992). Some evidence suggests that social behaviors such as these may influence smoking abstinence (Christakis & Fowler, 2008; Mermelstein, Cohen, Lichtenstein, Baer, & Kamarck, 1986; Mermelstein & Turner, 2006). A benefit of technology is that communication among group members can occur through online social media platforms. Moreover, research suggests that practitioners are more willing to adopt treatments that use social components relative to those that use only tangible reinforcers (Kirby, Benishek, Dugosh, & Kerwin, 2006).

Meredith et al. (2011) developed and tested an internet-based group CM program to promote smoking cessation by integrating independent and interdependent group contingencies. In other words, some reinforcers were available based on individual performance, and some were based on group performance. This arrangement was called a "mixed" group contingency. Participants could also provide and/or receive encouragement, feedback, and support via a discussion board integrated into the Mōtiv8 architecture. Using a multiple baseline design, Meredith et al. found that fewer than 1% of CO samples submitted during baseline were negative for smoking, compared to 57% submitted during the treatment phase. In addition, 65% of participants' comments on the online peer support forum were rated as positive by independent observers. This study demonstrated the feasibility, acceptability, and preliminary efficacy of internet-based Group CM. However, data from this experiment could not be used to assess the independent effects of social support and monetary group contingencies on smoking cessation.

Meredith and Dallery (2013) used a 2 x 3 factorial design to assess the effects of social support (first factor: presence or absence of support forum) and monetary contingencies (second factor: no vouchers, independent contingency, interdependent contingency) on smoking abstinence. The results suggested that social support did not impact outcomes. That is, although discussion board posts were rated as positive, they were also infrequent and did not appear to promote abstinence. Participants' responses to open-ended questions on the treatment acceptability questionnaire indicated that unfamiliarity with teammates may have hindered communication and decreased the value of social feedback.

The monetary group contingencies increased the percentage of negative samples from 1% during initial setup to 56% during the independent contingency condition and 53% during the interdependent contingency condition. Thus, interdependent contingencies alone were shown to promote brief abstinence. The interdependent contingency specified that all group members' COs had to reach criterion for a reinforcer: if one member failed then all failed. Although the percentage of negative samples submitted by participants was similar across both voucher conditions, the cost of vouchers was four times higher during the independent contingency condition (M $28.85) relative to the interdependent contingency condition (M $6.47). This suggests that interdependent contingencies may represent a more cost-effective alternative to independent contingencies.

Despite the potential cost-effectiveness of group contingencies, treatment acceptability data indicate that a strict interdependent contingency arrangement was less preferred than independent contingencies among some participants, especially those with no means to communicate with their teammates. Thus, Dallery, Meredith et al. (2015) investigated the effects of mixed versus full interdependent group contingencies. As expected, both arrangements promoted higher rates of abstinence compared to baseline control levels, but the differences in negative COs during treatment were not statistically significant (49% vs. 32% in the mixed versus full group contingency groups). Also, not surprising given the differences in negative COs, the payout in the mixed group was higher ($190) than in the full group contingency ($34). There were no statically significant differences in acceptability ratings of the two procedures, but attrition was higher in the full group arrangement compared to the mixed arrangement (36.4% and 23.8%, respectively). Several participants communicated that the social, cooperative component of the intervention was a deterrent to participation.

Taken together, these studies suggest that technology-based group contingencies are feasible, most participants were supportive, and most participants enjoyed communicating with other smokers trying to quit. One advantage of technology is that one size need not fit all: independent, dependent, and/or interdependent contingency arrangements could be delivered in a single platform. A participant could sample from the various arrangements, and then select the one that he or she prefers. As one participant suggested in the Dallery, Meredith et al. (2015) study, the intervention could be tailored based on whether an individual would be "better in a group or alone." Groups of smokers (i.e., teams) could even compete against other groups. Indeed, "gamifying" aspects of technology-based CM may enhance scalability, efficacy, and long-term engagement (Morford, Witts, Killingsworth, & Alavosius, 2014; Raiff, Fortugno, Scherlis, & Rapoza, 2018).

Deposit Contracts

Although internet-based methods circumvented some potential barriers to CM treatment, the financial costs associated with CM may also limit their application (Petry, 2010). Dallery, Meredith, and Glenn (2008) explored a method known as deposit contracting to offset voucher costs and promote abstinence. Deposit contracting has a long history as a way to reduce or eliminate a range of problem behaviors, including cigarette smoking (Bowers, Winett, & Frederiksen, 1987; Paxton, 1980, 1981; Winett, 1973). Most of these procedures specified that an initial monetary deposit (typically about $50) could be recouped based on smoking reductions and abstinence. However, deposit reimbursement was typically contingent upon self-reports of smoking abstinence, rather than biochemical verification of abstinence.

Dallery et al. (2008) assessed the effects of a deposit contract to deliver technology-based CM to promote smoking cessation. A deposit group was compared to a standard voucher delivery group in which no deposit was required ($n = 4$ per group). The deposit was set at $50 so that it would not be unduly prohibitive, and to be consistent with the relatively low amounts offered in previous studies that used a deposit contract (e.g., Paxton, 1980, 1981, 1983; Winett, 1973). Participants in the deposit group could recoup their $50 deposit for evidence of smoking reductions and abstinence (i.e., CO $\leq$ 4 ppm), plus an additional $28.80 if they maintained abstinence during the entire intervention. Participants in the no deposit group could earn $78.80 for continuous abstinence. Sixty-five percent of the samples were negative during the abstinence induction phase in the deposit group, whereas 63% of the samples were negative in the abstinence induction phase in the no-deposit group (missing samples were considered positive). Both groups achieved similar rates of abstinence, but the cost in vouchers approached $200 in the no-deposit group, compared to a small surplus ($43.10) in the deposit group.

One concern with deposit contracts is that a $50 deposit may be prohibitive, in particular given the disproportionate number of economically disadvantaged smokers (Centers for Disease Control & Prevention, 2015; Halpern et al., 2015). Thus, Jarvis and Dallery (2017) explored the feasibility and utility of self-tailored deposit contracts. In Experiment 1, nine participants deposited self-selected amounts that could be earned back for meeting CO goals. During treatment, 47% of samples were negative compared to 1% during baseline. Experiment 2 assessed whether a "clinic match" of participant's deposits, up to $50, would enhance outcomes. Ten participants enrolled, and no samples met the criterion during baseline but 41.5% were negative during treatment. The average deposit was $82 in Experiment 1 and $49 in Experiment 2. The clinic match did not enhance outcomes. The deposit contract arrangements eliminated voucher costs, even when incorporating a clinic match. After payments to participants, $332.66 was left in surplus and donated to charity.

Deposit contracts may not only offset voucher costs, they may mitigate a public policy concern with paying people to change behavior (Madison, Volpp, & Halpern, 2011; Sykes-Muskett, Prestwich, Lawton, & Armitage, 2015). In addition, they could be useful to the extent that a pure monetary reinforcer-based intervention may encourage individuals to "fake" a given behavior (e.g., smoking) to enroll in the intervention. Although alternative funding strategies may be preferred such as insurance reimbursement for CM treatment, a deposit contract method may be acceptable and efficacious for a sizeable enough portion of smokers and stakeholders to deliver a public health impact. The acceptability of a deposit—the number of individuals who actually make a deposit—will depend on a host of factors (Halpern, Asch, & Volpp, 2012; Stedman-Falls, Dallery, & Salloum, 2018). A large, randomized controlled study found poor acceptability (Halpern et al., 2015), whereas other, smaller studies have found good acceptability (Dallery et al., 2017; Jarvis & Dallery, 2017). The reasons for these differences are unknown. It is clear that more research is needed to assess variables that influence acceptability. Electronic web or mobile payment methods to enable deposits may lower the response effort relative to in-person methods therefore increase acceptability for some individuals. One deposit contract weight loss program delivered over the internet, DietBet, has reached over 700,000 individuals, and more than $60 million has been awarded to those who met their goals (Leahey & Rosen, 2014). The platform also incorporates a gamified group contingency in which successful individuals split the pool of initial deposits at the end of the program. A similar platform, QuitBet, has been launched for smoking cessation, which uses breath CO monitoring to verify smoking status.

Nationwide Access to Technology-Based CM

In most internet-based studies (and no studies using mobile methods, see below) participants were enrolled from local communities or specific subregions of the United States (e.g., Appalachian Kentucky; Stoops et al., 2009). In contrast, Jarvis and Dallery (2017) recruited participants from anywhere in the United States, and the 19 participants who enrolled resided in 13 states. There was no in-person contact with participants during the intervention (except equipment delivery for two local participants to avoid unnecessary shipping costs); all procedures were conducted remotely via the internet. Deposits were made as one lump-sum payment online using PayPal (a popular and secure e-business that manages money transfers and deposits), and earnings were also delivered via PayPal.

Likewise, Dallery et al. (2017) capitalized on the reach of the internet and recruited qualified smokers from anywhere in the contiguous United States. Smokers from 26 states were enrolled. Participants were randomized to earn monetary reinforcers (up to $480 over 7 weeks) based on meeting CO abstinence goals (n = 48; abstinence contingent group), or based on submitting CO samples (n = 46; control group). All study procedures (monitoring, reinforcer delivery) were conducted using the Mōtiv8 platform described above. Both groups also received the same instructions to meet the CO-based goals. A $50 deposit was required in both groups that could be recouped from initial earnings. During the two treatment phases when negative COs were the goals, there were significant differences in negative COs (53.9% in the abstinence contingent group and 24.8% in the control group during the Abstinence Induction phase, and 43.4% the abstinence contingent group and 24.6% in the control group during the Thinning phase). Figure 1 shows smoking status across all study phases for all participants.

Participants also found that the intervention was acceptable. A portion of individuals (13.5%), however, elected not to participate in the study and they cited the deposit as their main reason. Of those who enrolled, the highest rated items on a Treatment Acceptability Questionnaire concerned the ease of the intervention, the ability to view graphed CO progress, and earning money (all were rated > 80 on a 0–100 scale). These results are consistent with previous assessments of treatment acceptability of technology-based CM. Raiff, Jarvis, Turturici, and Dallery (2013) found that a number of stakeholders, including smokers, health-care professionals, and nonsmokers, indicated that technology-based CM was acceptable. Of the health-care providers, 81% (n = 113) reported that they would be very likely to recommend the intervention to patients.

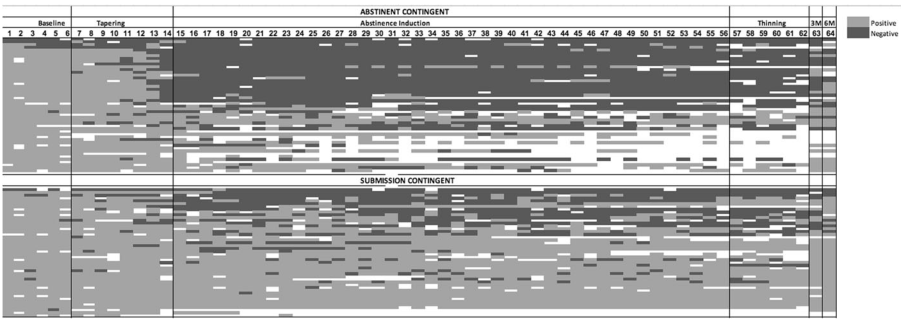

Fig. 1 Smoking status as assessed by breath CO for each participant across all study phases in Dallery et al. (2017). Each line represents a different participant. Negative results are indicated by dark gray shading, positive results are indicated by light gray shading, and missed samples are indicated by spaces (missing samples counted as positive). The final two points on each graph indicate the CO results for the 3- and 6-month follow-up visits

Mobile Contingency Management

Research has revealed that internet-based CM is accessible to a wide range of individuals. Advances in mobile technology, however, offer even greater reach. The number of mobile phone subscriptions now exceed the global population, and over 90% of the global population can access the internet via mobile phone (ITU, 2018). Further, compared to white Americans in the United States, black and Latina/o groups report equivalent rates of smartphone ownerships (77% for whites, 72% for blacks, and 75% for Hispanics [Perrin, 2017]). Blacks and Hispanics use their smartphones more often for health-related activities like searching for health information compared to whites (Perrin, 2017). Although smartphone ownership is less prevalent among low-income individuals, a recent study found that 94% of the homeless adults surveyed were current mobile-phone owners, and more than half owned smartphones (primarily Android; Rhoades, Wenzel, Rice, Winetrobe, & Henwood, 2017). Mobile CM interventions used with both nonminority and minority ethnic and racial groups offers great potential to eliminate the "digital divide" and address health-care disparities that exist in many traditional models of care (Gibbons et al., 2011).

Cigarette Smoking

Hertzberg et al. (2013) conducted the first mobile CM study. Instead of using web cameras to verify breath CO status and authenticate the end-user, the authors used the built-in digital camera. Hertzberg et al. enrolled 22 participants with posttraumatic stress disorder (PTSD). Comorbid smoking is more than double in this population, with about 40% smoking cigarettes versus approximately 15.5% in the general population (Kearns et al., 2018). In addition, these smokers often experience more severe withdrawal symptoms and have lower quit rates than in the general population. Nevertheless, in the Hertzberg et al. study, which was a small RCT, abstinence at 4 weeks was 82% in the CM group compared to 45% in a noncontingent control group. Participants in both groups also received pharmacotherapy (nicotine replacement or bupropion) and two counseling sessions. In addition to individuals diagnosed with PTSD, higher rates of smoking are also observed in individuals diagnosed with attention deficit hyperactivity disorder (ADHD). Dan, Grabinski, and Raiff (2016) used a multiple-baseline design with three smokers diagnosed with ADHD, and they found that smartphone-based CM decreased breath CO from a mean of 24 ppm at baseline to a mean of 6 ppm during treatment.

Carpenter et al. (2015) used mobile CM with homeless adults, among whom approximately 80% report smoking cigarettes. Homeless populations also exhibit high rates of psychiatric comorbidity. In this single-arm A-B study, participants (n = 25) were loaned smartphones for a 4-week mobile CM intervention in conjunction with pharmacotherapy (i.e., nicotine patch and bupropion) and in-person cognitive behavior therapy (CBT). Adherence to the CO video submission process was excellent (median adherence above 90%). Point prevalence abstinence, defined as 7 days of continuous negative COs (CO < 6ppm), was 0% during the baseline condition versus approximately 50% at 4 weeks.

Alessi, Rash, and Petry (2017) used basic cell phones instead of smartphones to deliver CM for smoking in a RCT. CM plus usual care (n = 45) was compared to usual care alone (n = 45), which consisted of pharmacotherapy (i.e., nicotine patch) and twice weekly counseling sessions conducted remotely via telephone. Interactive Voice Response (IVR) technology prompted CO submissions. Participants in both groups were contacted 1–3 times per day at random times between 7:00 AM and 10:00 PM to self-report their smoking status and submit a CO sample. Participants submitted the video using multimedia messaging, which obviated the need for a data or Internet access plan. Videos had to be submitted within 2 hours of the prompt. Adherence with CO video submissions was higher in the mobile CM group than usual care (84.5% vs 63.6%, respectively). Results indicated that 82% of mobile CM vs. 41% of usual care participants were abstinent at 4 weeks, and 21% versus 16% at 24 wks.

A mobile CM study by Kong, Goldberg, Dallery, and Krishnan-Sarin (2017) is noteworthy for two reasons. First, daily adolescent smokers were enrolled in the study (n = 15). Second, the monitoring procedures included breath CO during the first 2 weeks of treatment and then a transition to less frequent, saliva-based cotinine samples for the last 2 weeks. Cotinine is a metabolite of nicotine and can be detected on saliva for up to 3 days. Text messages were sent at random times 3 days per week, and then participants video recorded a cotinine sampling procedure. Although the ABC study design (i.e., CO submission, CM based on CO, and CM based on cotinine phases), in addition to the introduction of cognitive-behavioral therapy, precludes statements about CM efficacy, the results indicated increases in abstinence relative to baseline phases. Negative COs increases from 57% during baseline to 86% during the 2-week CO-based treatment. Sixty-seven percent of the cotinine samples were negative. Although the cotinine sampling was less frequent than the CO procedures, participants rated the cotinine sampling less favorably than CO. Forty-one percent rated the cotinine procedure as somewhat or very difficult, compared to 0% for the CO sampling procedure.

Alcohol Use

Despite the success of CM interventions with other substance-use disorders, alcohol use has rarely been a target of CM. A primary reason is that alcohol is rapidly metabolized, and therefore individuals must be tested frequently for evidence of alcohol use. Technology-based methods to monitor alcohol use frequently are now available. Alessi and Petry (2013) conducted a small RCT that was similar to the one described earlier for cigarette smoking (Alessi et al., 2017). Participants used basic cell phones to video record themselves exhaling into an alcohol breathalyzer to measure breath alcohol content (BAC). Participants were prompted via IVR 1–3 times per day to submit a video, and they were required to submit their video within 1 hour of the request because of the short half-life of BAC. Participants in the mobile CM group (n = 15) submitted negative BAC breathalyzer tests on 87% of video submissions, compared with 67% of monitoring only control participants (n = 15). Mobile CM participants also had a significantly longer period of being continuously alcohol free (mean = 17 days) relative to the control group (mean = 6 days). Adherence with procedure for submitting videos within 1 hour of the request was high for both groups (mean CM = 91% vs. mean monitoring only = 86%).

A potential limitation of technology-based CM studies discussed thus far is that a researcher or clinician must verify submitted videos to authenticate the end-user, and to assess the procedural integrity of the sampling procedures (e.g., that breath is being expelled). To overcome these limitations, a new BAC breathalyzer called Soberlink (Soberlink Healthcare, LLC, Huntington Beach, CA) includes cellular service and an integrated web camera. During the exhalation process a picture is taken of the user and his or her identity is automatically confirmed using facial recognition software. Koffarnus, Bickel, and Kablinger (2018) randomly assigned participants with alcohol use disorder to a contingent (n = 20) or noncontingent (n = 20) control group. Participants submitted three Soberlink samples per day, separated by at least 6 hours. The specific time windows were agreed upon between the participant and the experimenter. Of the submissions provided, 68% of the pictures were successfully approved via the facial recognition software, and unapproved images were typically due to poor lighting or the participant wearing glasses. In cases where images were not approved, study staff validated the pictures manually and informed the participant of the outcome via text message. Koffarnus et al. reported large differences in the percentage of negative samples in CM (85%) versus control (35%) participants. Because of the schedule of BAC monitoring in this study, a few participants reported some undetected drinking; however, this does not diminish the clinically significant effects of CM in this study.

To detect drinking more continuously than discrete breath-based methods, the "secure continuous remote alcohol monitor" (SCRAM) measures alcohol 24 hours a day. The SCRAM detects alcohol excreted on the skin (i.e., transdermally), which is secured around an ankle. SCRAM data, collected every 30-minutes from the anklet, can be transmitted via a modem or downloaded directly from the device. Several recent studies have explored the feasibility, acceptability, and preliminary efficacy using SCRAM to reinforce alcohol abstinence (Barnett et al., 2017; Barnett, Tidey, Murphy, Swift, & Colby, 2011; Dougherty et al., 2014; Mathias et al., 2018). In a small RCT, Barnett et al. (2017) assigned heavy drinkers to either a mobile CM intervention with monetary reinforcers delivered for SCRAM verified alcohol abstinence (n = 15) or a noncontingent (NC) control group that earned reinforcers independent of SCRAM verified abstinence (n = 15). During a 1-week baseline condition, both groups had a low percentage of days without SCRAM or self-reported alcohol use (CM = 19% vs. NC = 23%). During the 3-week intervention period, CM participants showed a significant increase in the percentage of days without alcohol (54%) whereas NC participants did not (31%). The CM group also had a longer sustained period without alcohol during the intervention (CM = 8 days vs. NC = 3 days).

Cigarette Smoking and Cannabis Use

Beckham et al. (2018) used a mobile CM intervention to target cigarette smoking and cannabis in a small pilot study (n = 5) lasting 4 weeks. The intervention also included cognitive-behavioral and nicotine-replacement therapy. Treatment among dual users of cigarettes and cannabis is challenging because cessation of one substance is often associated with increased use of the other, and among cannabis users continued cigarette smoking is associated with poorer outcomes (Akre, Michaud, Berchtold, & Suris, 2010; Peters, Budney, & Carroll, 2012). A novel and important feature of this study was the ability to detect THC in oral fluid using a swab and a home-based test kit. The oral detection procedures were conducted at the same time as the breath CO procedures (i.e., twice per day), and they were video recorded at the same time. Agreement between two independent raters of the test strips was 100%, and in only

1% of the videos were control strip results illegible. Schedules of reinforcement were arranged for each behavior separately, and additional earnings were possible for dual abstinence. Two out of the five participants initiated abstinence from both substances, and three out of five showed at least 7 days of abstinence from both substances. Because several treatments were introduced simultaneously, the role of CM in producing these outcomes was unclear. Nevertheless, the results suggest that the procedures were feasible and acceptable. More work is necessary to explore the effects of targeting other health-risk behaviors in the context of SUDs (e.g., Dennis et al., n.d.).

Although in-person CM has been employed to target dual- or polydrug use (Downey, Helmus, & Schuster, 2000; Epstein et al., 2009), to our knowledge it has not been used to concurrently target other, nondrug health behaviors. A growing number of researchers are recognizing the important interactions between health behaviors (Prochaska, Spring, & Nigg, 2008; Spring, King, Pagoto, Van Horn, & Fisher, 2015; Spring, Moller, & Coons, 2012). For example, sedentary behavior, poor sleep quality, unhealthy eating, problem alcohol consumption, and smoking cigarettes may have additive or interactive effects in increasing risk for disease (Spring et al., 2015). Targeting multiple health behaviors with CM therefore may have large effects in lowering risk of disease, and advances in technology may be instrumental in such a treatment (Spring et al., 2018). Indeed, technology can be employed to unobtrusively and continuously detect virtually all health-risk behavior (a current exception is eating behavior; see Dallery et al., 2013 for a review).

The Future of Digital and Behavioral Technology in the Treatment of SUDs

In a relatively short span of 14 years, we have seen several advances in technology-based CM. Advances in information technology has expanded the geographical reach of CM from local to nationwide; advances in sensors have permitted detection of cigarette, alcohol, and cannabis use with mobile phones; and advances in software have allowed automation of all aspects of technology-based CM (i.e., monitoring, reinforcer delivery, user authentication). It seems clear we will continue to see evolution of drug monitoring systems (Carreiro et al., 2016; Ferreri, Bourla, Mouchabac, & Karila, 2018; Meredith et al., 2014). For example, several companies are developing wrist-worn, continuous alcohol monitors (Wang, Fridberg, Leeman, Cook, & Porges, 2018), and at least one research group is developing an electrochemical tattoo to detect alcohol (Kim et al., 2016). It could argued that these monitors will be more acceptable to participants than the SCRAM ankle monitors, which resemble the ankle monitors used in law enforcement. The future of remote monitoring systems for illicit drugs (other than cannabis) is less clear. Although some predict that breath-based methods will be feasible within a decade (Amann et al., 2017), the performance and cost of these devices are unknown. Saliva-based testing may be more feasible in the short term (Beckham et al., 2018), but more research is needed on acceptability and efficacy. In addition, thorny issues related to privacy and confidentiality will need to be addressed given the implications of detecting and transmitting evidence of illicit drug use.

Advances in technology-based CM are occurring concurrently with a new age of digital therapeutics. Digital therapeutics include a range of technology-delivered treatments in addition to CM treatments. The first digital therapeutic cleared by the Federal Drug Administration (FDA) is reSET (Campbell et al., 2014; Zagorski, 2017). reSET is a mobile phone-based program the delivers the skills development component of Community Reinforcement Therapy. It functions in conjunction with standard outpatient treatment for opioid alcohol, cocaine, marijuana, and stimulant SUDs, and it also includes an in-person CM component. reSET is available by prescription, and it can be reimbursed as a product via pharmacy and medical benefits. The FDA also cleared a Bluetooth-enabled mobile CO device, called Pivot, which also includes mobile phone based therapeutic content and personalized coaching (Patrick, Fujii, Glaser, Utley, & Marler, 2018). Pivot is primarily marketed to employers, which is a promising strategy because smokers cost employers about $6,000 per year more than nonsmokers (Berman, Crane, Seiber, & Munur, 2014). A technology-based CM program has the potential to become a digital therapeutic, which could increase its scalability and the possibility of insurance reimbursement.

In addition to advances in digital technology, we also need new applications of behavioral technology. Technology-based methods have already afforded novel approaches to arrange deposit contracts, target more than one health-risk behavior, and arrange group contingencies. McPherson et al. (2018) discussed some optimization strategies to promote abstinence in the context of CM, such as tailoring reinforcer magnitude, shaping procedures, and extending the duration of treatment. Of these strategies, extending the duration of CM is perhaps the most critical missing ingredient in the context of technology-based CM. The studies discussed in this article were relatively brief. Brief CM could generate meaningful health outcomes during pregnancy, or during perioperative care, or perhaps during critical periods during adolescence as a prevention strategy. Nevertheless, most applications of CM target unhealthy behaviors that have persisted for 10–20 years or more. None of the studies discussed above yielded statistically significant differences between groups at long-term follow-up assessments. Some, however, have shown potential for long-term success, in particular those that include treatment components that target additional behavioral mechanisms (e.g., skills building, motivational enhancement). For example, Carpenter et al. (2015) found smoking abstinence rates of 65% and 60% at 3 and 6 months after a mobile CM intervention, respectively. A control group was not used. The mobile intervention included weekly cognitive-behavioral therapy and pharmacotherapy. Although the roles of these components in long-term outcomes is unclear, exploring added treatments that focus on other behavioral mechanisms is a worthy area for future research.

In addition, Silverman and colleagues have demonstrated the viability and efficacy of CM as a long-term maintenance intervention in the treatment of drug dependence (e.g., Aklin et al., 2014; DeFulio, Donlin, Wong, & Silverman, 2009). The CM interventions were maintained for 1–4 years. Technology-enabled CM could make it relatively efficient to monitor some forms of drug use (e.g., smoking, alcohol, cannabis) for extended durations, and automation means that CM could be implemented with low staff burden and high fidelity. As such, technology-based CM may result in a cost-effective intervention (Murphy, Campbell, Ghitza, Kyle, Bailey, Nunes, & Polsky, 2016). Examining the acceptability, efficacy, and cost effectiveness of a maintenance intervention are important next steps in the evolution of technology-based CM. Developing and refining a maintenance intervention will require careful application of the conceptually systematic principles of behavior analysis. The effectiveness of digital technologies in the field of substance abuse will be only as good as the principles behind them.

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