Impact of Ecological Momentary Assessment Participation on Short-term Smoking Cessation: Results from the quitSTART EMA Incentivization Trial

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Abstract

Background: Cigarette smoking is the leading cause of preventable mortality in the U.S. Cessation interventions delivered through smartphone applications (apps) can reach large populations of individuals who smoke. Ecological Momentary Assessment (EMA), a feature often included in existing cessation apps, can be used to track behaviors and other important constructs and to inform Just-In-Time Interventions. However, the influence of EMA engagement on smoking cessation is unknown. Additionally, the implications of incentivizing the use of EMA for cessation outcomes is currently unknown. The National Cancer Institute's publicly available smoking cessation app, quitSTART, includes a two-week voluntary EMA protocol (42 total EMA prompts), which provides an opportunity to explore the impact of EMA incentivization on smoking cessation.

Objective: This study aimed to examine the influence of app-based EMA participation on smoking cessation for people who are incentivized to use EMA compared to those who are not incentivized (representing the current implementation of EMA within quitSTART).

Methods: N=152 U.S. adults were recruited from online and text-message sources into a randomized controlled trial. All eligible participants were randomized to either non-incentivized EMA or incentivized EMA. Participants completed baseline, two- and four-week assessments. The primary outcome of interest was seven-day point prevalence abstinence measured at two and four weeks after app download. Average EMAs completed by arm was compared using a t-test. Firth logistic regression modeling was used to determine the association between arm and smoking abstinence at two and four weeks, adjusted for smoking frequency and concurrent use of other tobacco products.

Results: The mean number of EMAs completed was 13.3 in the incentivized arm (range=0-40) and 4.7 (range=0-28) in the non-incentivized arm (p<.001). Cessation rates were 9.0% and 20.3% at 2-weeks (p=.062), and 17.5% and 36.6% at 4-weeks (p=.013) in the incentivized arm and non-incentivized arm, respectively. Arm was not associated with cessation in adjusted models (AOR, two-weeks: 0.60, 95% CI: 0.21-1.73, AOR four-weeks: 0.51, 95% CI: 0.22-1.19). Sensitivity analyses coding missing responses as smoking found that at four weeks, those in the incentivized arm were less likely to report abstinence (AOR: 0.41, 95% CI: 0.18-0.93).

Conclusions: This study attempted to isolate and examine the effect of incentivizing EMA engagement on smoking cessation success for adults using a smartphone app to quit. While participants randomized to incentivization of EMA showed higher engagement with this feature, our findings suggest that there was no additional short-term cessation benefit from this engagement. Sensitivity analyses found a potential benefit for allowing autonomy over the use of app features, despite the ability of EMA completion to provide real-time tailored cessation support. Clinical Trial: clinical trials.gov identifier: NCT04623736

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Results: The mean number of EMAs completed was 13.3 in the incentivized arm (range=0-40) and 4.7 (range=0-28) in the non-incentivized arm (p<.001). Cessation rates were 9.0% and 20.3% at 2-weeks (p=.062), and 17.5% and 36.6% at 4-weeks (p=.013) in the incentivized arm and non-incentivized arm, respectively. Arm was not associated with cessation in adjusted models (AOR, two-weeks: 0.60, 95% CI: 0.21-1.73, AOR four-weeks: 0.51, 95% CI: 0.22-1.19). Sensitivity analyses coding missing responses as smoking found that at four weeks, those in the incentivized arm were less likely to report abstinence (AOR: 0.41, 95% CI: 0.18-0.93).

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Keywords: mHealth, smoking cessation, smartphone applications, ecological momentary assessment

Introduction

Cigarette smoking is the leading cause of preventable mortality in the U.S. and causes multiple cancers, including lung, colorectal, and liver cancers.[1–3] Approximately 28.3 million U.S. adults currently smoke cigarettes.[3] Although more than 50% of people who smoke attempt to quit smoking each year, only 8% are successful.[4] The use of evidence-based cessation treatment (e.g., cessation medications, cessation counseling) can substantially improve the odds of successfully quitting.[5] However, most people try to quit smoking without assistance,[6–8] which has been shown to be less effective than quitting with assistance.[9] Therefore, connecting people who want to quit smoking with smoking cessation treatment is an important public health goal.[8]

Smoking cessation programs using mobile health (mHealth) technologies have the potential to cost-effectively reach individuals who smoke at a population level.[10–12] Specifically, mHealth cessation interventions delivered through smartphones can reach a large population of individuals who smoke in the U.S., as 90% of U.S. adults own a smartphone.[13] Smartphone use is also prevalent across sociodemographic groups in the U.S.,[13] which can help to deliver interventions to a diverse population and reduce smoking-related health disparities.[14] The most recent examination of smoking cessation applications (‘apps’) found over 500 English language apps are available to smartphone users, and at the time of the study, these apps had approximately 3.2 million U.S.-based downloads.[15]

Several studies have demonstrated the effectiveness of smartphone apps in aiding smoking cessation.[15–20] Yet, little is known about the influence of use of specific app features (e.g., self-monitoring of smoking and mood, games, mindfulness training, etc.) on smoking cessation. Limited evidence suggests that engaging with certain features like tracking cravings and engagement with quit plans can positively influence cessation outcomes.[21,22]

One such app feature that can provide insight into areas such as smoking behavior, key contextual factors associated with smoking, and environmental influences on smoking behaviors is app-based ecological momentary assessments (EMAs).[23] EMAs involve frequent, repeated sampling

of individuals' environments, affective states, and behaviors.[18] One advantage of utilizing EMAs is that they provide data from participants in their natural environments, giving access to responses that may not be accurately collected in a research setting (e.g., using periodic mailed questionnaires). EMAs can also reduce biases related to retrospective recall by collecting real-time data.[23,24] Increasingly, EMAs are being leveraged to inform the development of Just-In-Time Adaptive Interventions (JITAI),[25] which involve the provision of adaptive support to individuals at a particular time of day, location, or moment of intervention need, using data collected through EMAs or sensors.[26] In addition, tracking (e.g., of smoking behaviors, cravings, quit progress), which is commonly done through EMA, is the most frequently reported feature included in smoking cessation apps.[27] Therefore, it is imperative that we understand the effect of EMA engagement on cessation outcomes.

To date, many smartphone-based cessation interventions have incorporated EMA functionality in some capacity within a smoking cessation app.[16,18,19,28–36] Collectively, these studies show promise for the potential of apps that integrate EMA as a cessation strategy. However, questions remain about how EMA completion specifically impacts cessation outcomes. Importantly, in many cases where EMA has been used as part of the intervention design, both study arms have been asked to participate in the EMA protocol. For example, in a study conducted by Garrison et al., participants in both the intervention and control group received EMA prompts six times a day for 22 days asking all participants to report current activities in progress, awareness, focus, feelings, cigarette cravings, mood, and number of cigarettes smoked.[31] Schwaninger et al. encouraged all participants to complete a daily EMA of exhaled carbon monoxide.[32] Bricker et al. compared a cessation app that included EMA (iCanQuit) to the NCI QuitGuide app, which does not include EMA, potentially providing some evidence about the impact of EMA on cessation.[37] However, there were multiple differences between the two apps, making it difficult to isolate the features that made iCanQuit more efficacious than QuitGuide.[37] To our knowledge, no study has directly compared

cessation outcomes within a single app by EMA participation levels.

Adding to these gaps in research is a lack of information about real-world smartphone-based EMA participation and smoking cessation. Specifically, when implemented in a real-world setting, mHealth application use is quite variable, and engagement (e.g., levels of app use) is generally low, across health behaviors.[38] Therefore, it is also important to consider how or to what extent EMA participation has been encouraged in prior studies, which may help to determine the potential benefit of EMA participation when apps with EMA are made available to the public. Within the existing literature examining the efficacy of smoking cessation apps, several studies have specifically described strategies used to encourage and maintain engagement in EMA completion.[15,16,26,29,34,38] For example, in Businelle et al., all participants were incentivized to complete the EMA protocol by having part of their participation incentive linked to EMA completion levels, with a baseline threshold of 50% completed to receive any EMA payment.[18,28] For Garrison et al., if participants decreased their EMA participation in the EMA protocol to a pre-specified level they would receive communication from study staff to encourage participation in EMAs.[31] For the iCanQuit study, staff were not involved in encouraging EMA participation, but in order for participants to gain access to specific content, continued smoking abstinence had to be reported through daily tracking, thereby encouraging use of tracking within the app.[17,37,39] Therefore, the data that have been generated from these clinical trials have limited utility for understanding app-based EMA participation when it is not incentivized or the effect of incentivizing the use of EMA on cessation outcomes.

quitSTART cessation application

The National Cancer Institute's Smokefree.gov Initiative provides free, publicly available smoking cessation resources to help people successfully quit.[40] One of these resources is quitSTART, a publicly available smoking cessation app.[41] Available to download on iOS and Android since 2013, the app is widely used, with 1,000-2,000 people downloading quitSTART each month. quitSTART provides intervention content in several ways. The user has access to sets of content, called "cards"

that are grouped into categories of information about smoking and health, cessation tips, inspirational quotes, and challenges; cards can be added into a user's "quit kit" to create a quit plan. Users can proactively (e.g., without responding to a prompt or push notification) create app entries to track cravings to smoke, if they smoked, and if they are "feeling down" or "feeling good".[41] Users who report a craving or smoking can "tag" these actions to a specific time of day or their current location and then receive supportive messages via push notifications during that time of day or the next time they return to a tagged location.

Starting in October 2017, built-in EMA capability was added to quitSTART. The EMA protocol is as follows: starting on the date of download, quitSTART users are automatically opted-in to the EMA protocol but may opt-out by turning off push notifications. During the first two weeks after app download, users are sent three EMA completion prompts a day for two weeks (n=42 total prompts sent). Users receive prompts at random times during three time periods each day and have one hour to respond after a prompt is sent. Prompts assess craving level, mood, and number of cigarettes smoked. Users who respond receive a tailored message based on their mood and craving level (Supplemental Table 1).

Previous descriptive evaluations of voluntary use of EMA within quitSTART have shown very low initial uptake. Specifically, between January and March 2018, 59% of quitSTART users had never completed an EMA prompt. Of those who completed any EMAs, 42% only completed one EMA prompt.[42] It is unknown whether the levels of EMA participation in this publicly available smoking cessation app impact smoking cessation outcomes. Therefore, the goal of this study was to examine the influence of app-based EMA participation on smoking cessation for people who are incentivized to use this feature compared to those who are not incentivized (representing the current implementation of EMA within quitSTART) using a randomized controlled trial. Given the reported cessation outcomes of existing apps that utilize EMA, we hypothesized that those randomized to receive incentives for completing EMAs would have higher odds of self-reported smoking cessation

rates at two- and four-weeks after app download.

Methods

Design

This single-blind (participant) randomized trial included 152 adults who smoke aged 18 and older. The recruitment period took place between October 2020 to April 2021. All participants provided informed consent prior to participation. Eligible participants were randomized prior to consenting to blind the participant to the investigational arm they were receiving. Specifically, participants were randomized to one of two conditions: non-incentivized EMA (control), or incentivized EMA. All data were collected online at three assessment points: baseline, two-weeks, and four-weeks post-enrollment. The study design and protocol were approved by the Institutional Review Board at the University of Virginia, (UVA SBS IRB protocol # 3643, clinical trials.gov identifier: NCT04623736).

Procedure

Participants were recruited using a mix of online, social media, and text-messaging methods. Specifically, a link to the study interest form was posted on the Smokefree.gov webpage for quitSTART during the entire recruitment period. In addition, a three-week social media campaign was implemented across Smokefree.gov's Twitter, Facebook, and Instagram accounts. In April 2021, a recruitment text-blast was sent to any enrolled users of the SmokefreeTXT text messaging cessation program. Recruitment materials instructed applicants to complete an online interest form that included sociodemographic information and smoking history. Research staff screened for eligibility and performed identity verification of all potentially eligible participants before being contacted for informed consent. A total of 1,066 interest forms were completed (Figure 1).

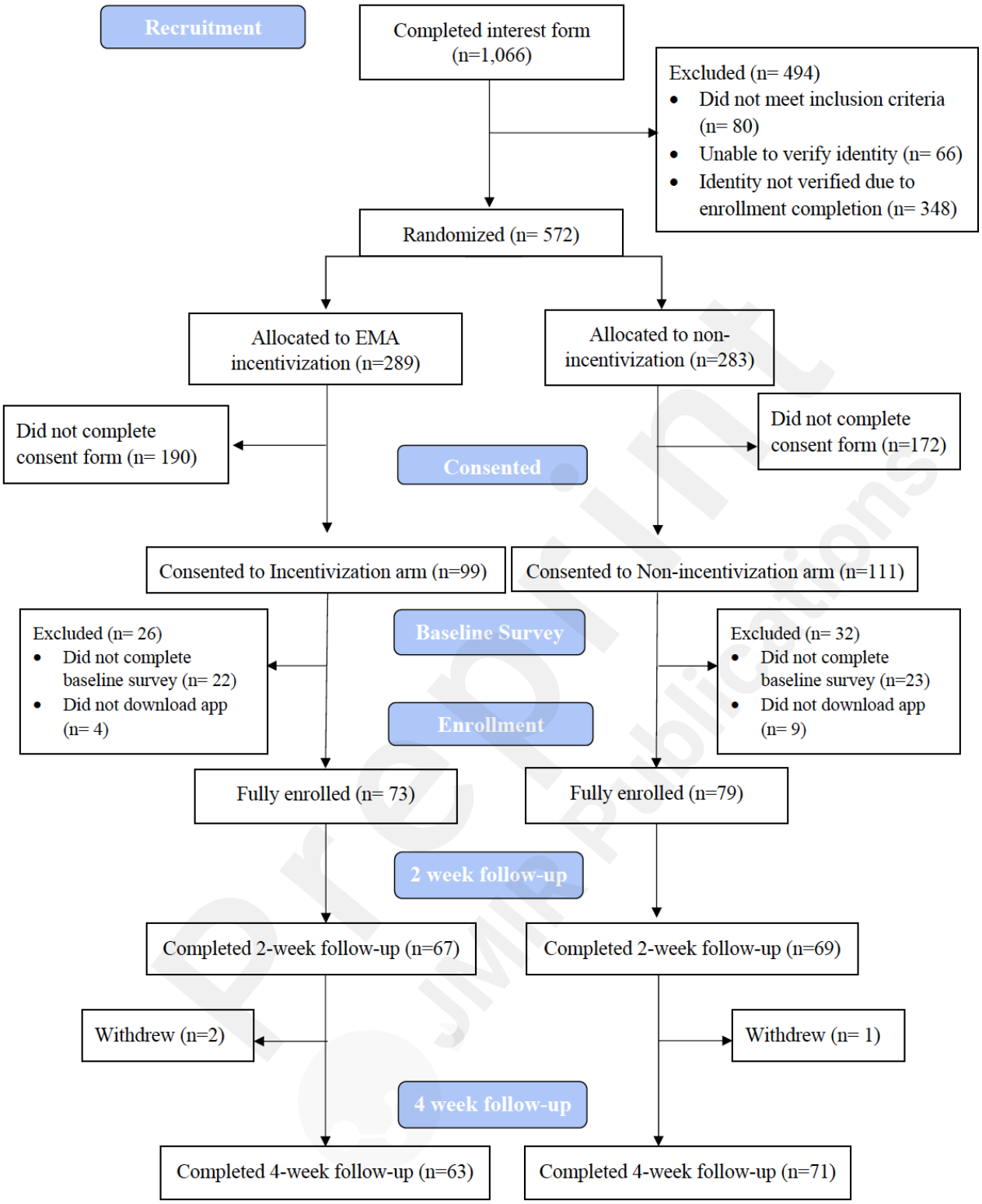

Figure 1. Consort Diagram

Eligible participants were required to meet the following criteria: (1) English speaking adults who smoke cigarettes living in the U.S., (2) not pregnant or trying to become pregnant in the next

month, (3) owned a smartphone, (4) identity could be verified using a commercial identity verification service,[43] and (5) consistent smoking information given between interest form and consent (i.e., reported current smoking on both the interest and consent forms). Individuals whose identities remained unclear were contacted by study staff to determine eligibility. All eligible participants were sent a notification to complete study enrollment by completing an online consent form and randomized 1:1 at the time of eligibility notification. Separate consent forms were used for participants in the non-incentivized EMA arm and incentivized-EMA arm, respectively. Information on the consent forms was identical with the exception of the compensation plan, which differed by arm (see *Randomized conditions* below).

After completing informed consent, all participants were sent the baseline survey to complete online. Following completion of the baseline survey, participants were given information about downloading quitSTART and were instructed to confirm download of the app with study staff. Participants were considered fully enrolled when they had completed the baseline survey and notified study staff that they had downloaded the app. Follow-up surveys were sent via email at two and four weeks after app download. Of 1,066 completed interest forms, n=572 were determined eligible and were randomized, n=210 consented to participate, and n=152 fully enrolled. Response rates to the 2-week and 4-week surveys were 89.5% and 88.2%, respectively, with no differences in response rates by arm.

Randomized conditions

Non-incentivized EMA arm. Participants randomized to the non-incentivized arm were instructed to use the app however they would like to, and that their compensation for participation depended only on survey completions. They received all quitSTART EMA notifications but were not incentivized based on their EMA completions. They were asked to use quitSTART for four weeks.

Incentivized EMA arm. Participants randomized to the incentivized EMA arm were informed that part of their compensation for study participation would be based on their level of EMA

participation. Specifically, those with higher levels of participation received higher compensation. Participants had to complete at least half of the programmed EMAs to receive compensation for the EMA portion of their incentive.[18,28] Participants in the incentivized EMA arm also received compensation for survey completions. They were asked to use quitSTART for four weeks. Total potential compensation between the two arms was identical.

Measures and coding

The baseline assessment included items measuring smoking frequency (daily or non-daily smoking), use of other tobacco products (coded as 'yes' for report of past 30 day use of cigar, pipe, hookah, electronic cigarette, smokeless tobacco, or snus, or 'no'), nicotine dependence (measured using Fagerstrom Test for Nicotine Dependence,[44] total score range: 0-10), use of menthol cigarettes (coded as 'yes' or 'no'), and previous quit attempts in the past 12 months (coded as 'yes' or 'no'). Alcohol consumption was also assessed using number of drinking days per week, average number of drinks consumed when drinking, and frequency of binge drinking). Self-efficacy to quit smoking,[45] motivation to quit smoking, and indicators of anxiety and depression,[46] were also collected. Demographic characteristics, including gender identity (coded as 'women,' 'man,' or 'another gender identity' (included transgender women, transgender man, non-binary, or "something else", combined due to small cell sizes), race (coded as 'black,' 'other', or white,'), ethnicity (coded as 'Hispanic or Latino' or 'Not Hispanic or Latino'), education (coded as 'less than high school,' 'HS or GED,' 'some college,' and 'college graduate or more'), marital status (coded as 'married/partnered,' 'divorced,' 'widowed,' 'separated,' and 'single, never married'), and sexual orientation (coded as 'straight,' or 'LGB+' (included gay or lesbian, bisexual, and 'something else')) was also collected.

Follow-up surveys at two and four weeks after app download assessed the primary outcome of interest: seven-day point prevalence smoking abstinence (responses to the question: "Have you smoked a cigarette (even a puff) in the past 7 days?" were 'yes' and 'no'). Additionally, continuous abstinence (responses to the question: "In the last two weeks [four for the 4-week follow-up], have

you smoked at all?" were 'yes,' 'no,' and 'not sure,' and were coded as 'yes' and 'no/not sure'), number of cigarettes smoked per day (for those who continued smoking), other tobacco product use (coded as 'yes' for report of past two week use of cigar, pipe, hookah, electronic cigarette, smokeless tobacco, or snus, or 'no'), quit attempts in the last two weeks (coded as any, or none), reasons for relapse (if still smoking), motivation to quit smoking (if still smoking), anxiety and depression, and perceived usability of the quitSTART app[47] were assessed in follow-up surveys.

Participants' total number of EMA completions was obtained from quitSTART app use data and calculated by summing the number of EMAs completed during the first two weeks after app download by study arm.

Statistical Analysis

All analyses were performed using SAS 9.4. Demographic and tobacco use characteristics of the sample were summarized overall and by randomized arm. To determine the impact of incentivization on EMA participation, total EMAs completed were compared by arm using a t-test. Given the overall study size and rarity of abstinence in the study population, Firth logistic regression modeling was used to determine the association between randomized arm and 7-day point prevalence abstinence, with one model for two-week and four-week abstinence, respectively. Given that participants were randomized before they were fully enrolled, there was potential for consenting and enrollment bias. Thus, demographic and tobacco use characteristics were also compared between randomized arms using chi-square and t-tests as appropriate and revealed statistically significant differences in the distributions of baseline smoking frequency, use of menthol cigarettes, and use of other tobacco products between those who consented but did not fully enroll to those who fully enrolled. To account for this potential bias, we also created models adjusting for these differences. Testing for the presence of collinearity revealed that use of menthol cigarettes and use of other tobacco products were correlated, and therefore, only one variable was selected for inclusion in the adjusted model. To determine which of the two variables to include in the final model, we calculated

the percent change in the estimate of the association between randomized arm and 7-day point prevalence abstinence to determine which potential covariate had the largest impact on the primary associations of interest (study arm and cessation). Inclusion of use of other tobacco products resulted in a 21% and 19% change in the point estimate of the impact of arm for two- and four-week cessation, respectively. Inclusion of menthol cigarette use resulted in a 16% and 15% change in the point estimate of the impact of arm for two- and four-week cessation, respectively. Therefore, two adjusted Firth logistic regression models were created including randomized arm, smoking frequency, and concurrent use of other tobacco products for two- and four-week cessation. As a sensitivity analyses, unadjusted and adjusted models were also created with missing responses for cessation coded as continued smoking.

Results

Most study participants were female (76.32%), white (78.29%), and not Hispanic or Latino (88.82%, Table 1). The average age of participants at study enrollment was approximately 45 years (SD= 12.45). Just under half (47.4%) of participants had a college degree or higher education. Participants reported low-to-medium nicotine dependence with an average Fagerstrom score of 4.71 (SD= 2.30). About one-third of participants reported use of other tobacco products (34.9%), and use of menthol cigarettes (32.9%). Less than a quarter of participants (22.37%) reported having tried to quit smoking within the last year.

Table 1. Demographic and baseline tobacco use characteristics overall and by study arm

Characteristics	Total (N=152) N (%)	Incentivized EMA (N=73) N (%)	Non-Incentivized EMA (N=79) N (%)
Age			
Mean (SD)	45.23 (12.45)	46.55 (11.94)	44.01 (12.86)
Gender[a]			
Female	116 (76.32)	58 (79.45)	58 (73.42)
Male	33 (21.71)	15 (20.55)	18 (22.78)
Race			
Black	19 (12.50)	6 (8.22)	13 (16.46)

Other	14 (9.21)	6 (8.22)	8 (10.14)
White	119 (78.29)	61 (83.56)	58 (73.42)
Ethnicity			
Hispanic or Latino	17 (11.18)	6 (3.95)	11 (13.92)
Not Hispanic or Latino	135 (88.82)	67 (91.78)	68 (86.08)
Education			
Less than high school	6 (3.95)	4 (5.48)	2 (2.53)
HS or GED	15 (9.87)	9 (12.33)	6 (7.59)
Some College	59 (38.82)	26 (35.62)	33 (41.77)
College Graduate or More	72 (47.37)	34 (46.58)	38 (48.10)
Marital Status			
Married/Partnered	79 (51.97)	39 (53.42)	19 (24.05)
Divorced	28 (18.42)	14 (19.18)	4 (5.06)
Widowed	6 (3.95)	4 (5.48)	2 (2.53)
Separated	8 (5.26)	4 (5.48)	14 (17.72)
Single, never married	31 (20.39)	12 (16.44)	40 (50.63)
Sexual Orientation			
Straight	120 (78.95)	60 (82.19)	60 (75.95)
LGB+	32 (21.05)	13 (17.81)	19 (24.05)
Smoking frequency			
Every day	140 (92.11)	71 (97.26)	69 (87.34)
Some days	12 (7.89)	2 (2.74)	10 (12.66)
Fagerstrom total score			
Mean (SD)	4.71 (2.30)	4.95 (2.36)	4.77 (2.37)
Concurrent use of other tobacco products			
Yes	53 (34.87)	19 (26.02)	34 (43.04)
No	99 (65.13)	54 (73.97)	45 (56.96)
Smokes Menthol Cigarettes			
Yes	50 (32.89)	17 (23.29)	33 (41.77)
No	102 (67.11)	56 (76.71)	46 (58.23)
Quit attempt in the last 12 months			
Yes	118 (77.63)	60 (82,19)	58 (73.42)
No	34 (22.37)	13 (17.81)	21 (26.58)

a. Total does not add to 100% due to missing or suppressed values due to small sample size.

Mean EMAs completed in the incentivized arm was 13.3 (range=0-40) and 4.7 (range=0-28) in the non-incentivized arm (p<.001, Figure 2). Cessation rates were 9.0% and 20.3% at 2-weeks (p=.062), and 17.5% and 36.6% at 4-weeks (p=.013) in the incentivized arm and non-incentivized arm, respectively (Table 2).

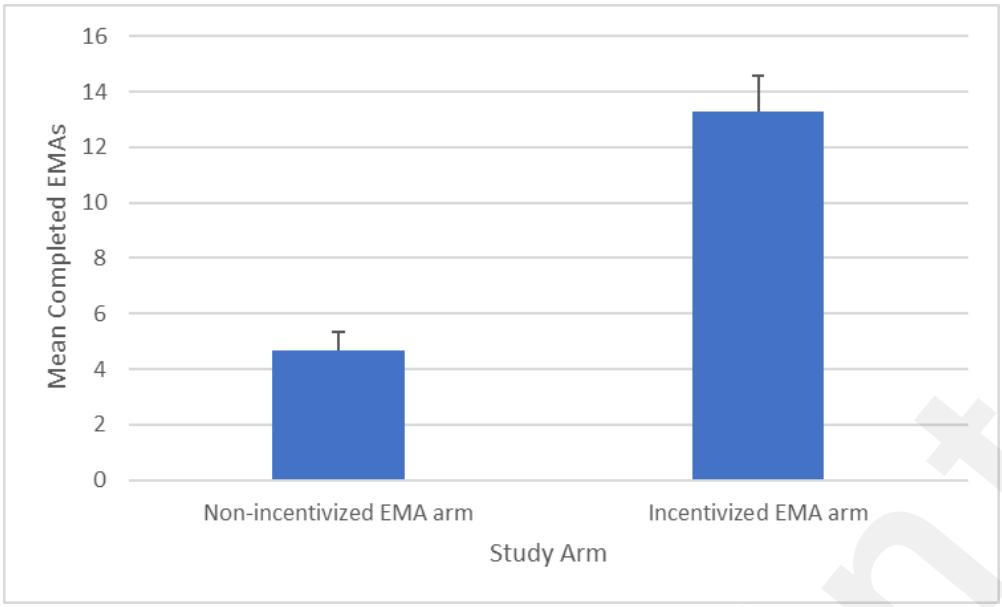

Figure 2. Mean EMAs completed by study Arm.

Table 2. Smoking cessation outcomes overall and by group

	Total N (%)	Incentivized EMA N (%)	Non-Incentivized EMA N (%)	Chi-square p-value
2 Weeks				
7-day abstinence				
Yes	20 (14.71)	6 (8.96)	14 (20.29)	.09
No	116 (85.29)	61 (91.04)	55 (79.71)	
4 Weeks				
7-day abstinence				
Yes	37 (27.61)	11 (17.46)	26 (36.62)	.01
No	97 (72.39)	52 (82.54)	45 (63.38)	

At two-weeks, incentivization was not associated with abstinence in the crude (OR: 0.39,

95% CI: 0.14-1.08) or adjusted models (AOR: 0.60, 95% CI: 0.21-1.73, Table 3). At four weeks, compared to participants randomized to the non-incentivized arm, those randomized to the incentivized arm had lower odds of abstinence in the crude model (OR: 0.37, 95% CI: 0.16-0.82); however, this association was no longer statistically significant in the adjusted model (AOR: 0.51, 95% CI: 0.22-1.19). Participants who reported having used other tobacco products in the past 30 days had 3.42 (95% CI: 1.27-9.26) and 2.71 (95% CI: 1.21-6.10) times the odds of abstinence at two- and four-weeks, respectively. Sensitivity analyses coding missing responses as smoking found that at four weeks, those randomized to the incentivized arm were less likely to report abstinence (AOR: 0.41, 95% CI: 0.18-0.93).

Table 3. Associations between incentivization arm and cessation

	Crude OR (95% CI)	Adjusted model[a] OR (95% CI)	Sensitivity Analyses[b] OR (95% CI)
2 Weeks			
Arm			
Incentivized EMA	0.39 (0.14-1.08)	0.60 (0.21-1.73)	0.50 (0.18-1.40)
Non-Incentivized EMA	Referent	Referent	Referent
Smoking frequency			
Everyday	Referent	Referent	Referent
Some days	4.58 (1.17-18.03)	3.69 (0.84-16.15)	2.94 (0.75-11.62)
Concurrent use of other tobacco products			
Yes	3.94 (1.47-10.52)	3.42 (1.27-9.26)	2.98 (1.12-7.96)
No	Referent	Referent	Referent
4 Weeks			
Arm			
Incentivized EMA	0.37 (0.16-0.82)	0.51 (0.22-1.19)	0.41 (0.18-0.93)
Non-Incentivized EMA	Referent	Referent	Referent
Smoking frequency			
Everyday	Referent	Referent	Referent

Some days	3.56 (1.02-12.49)	2.54 (0.67-9.65)	2.57 (0.73-9.03)
Concurrent use of other tobacco products			
Yes	3.21 (1.46-7.06)	2.71 (1.21-6.10)	2.58 (1.18-5.62)
No	Referent	Referent	Referent

a. Model adjusted for all listed covariates (smoking frequency and Concurrent use of other tobacco products)
b. Missing respondents coded as smoking at each respective time point.

Discussion

To our knowledge this is the first randomized trial designed to determine the impact of incentivized EMA completion on cessation outcomes. We hypothesized that increased EMA participation would be associated with higher rates of short-term abstinence, due to participants receiving more personally tailored content during the first two weeks of a quit attempt, as well as higher overall engagement with quitSTART. This hypothesis was informed by the success that previously tested apps have had in supporting cessation, where tracking is one of the most commonly included features,[15,17,18,37,39,48] and a recent meta-analysis showing that increased engagement within cessation apps was associated with abstinence.[49] We found that while incentivizing EMA completion did lead to participants completing more EMAs, it did not result in increased likelihood of cessation and potentially had a negative impact on short-term cessation outcomes.

Our results are similar to McCarthy et al. who randomized adults who were interested in quitting smoking into two levels of EMA intensity (once a day vs. six times a day).[50] While participants in the more intensive EMA arm had decreased cravings, anger, and anxiety, there was no association between EMA intensity and two-week cessation.[50] Given the widespread inclusion of EMA functionality in cessation apps, it is important that we understand the implications of using this feature. Future analyses should consider the impact of study arm on patterns of app use, as well as the association between levels of EMA completion and cessation to more fully understand how EMA engagement influences cessation outcomes.

In clinical trials, when EMA completion is necessary to inform Just-In-Time Intervention content, participation in EMA has been, necessarily incentivized.[18,28] However, once an application

becomes publicly available, resources and infrastructure may not be in place to provide this type of monetary incentivization for EMA completion. Assessing the impact of EMA incentivization on cessation is of the utmost importance so that we can better understand the utility of EMA if it is not incentivized (i.e., in real-world settings). The current study provides evidence that incentivizing EMA completion does result in greater engagement with EMAs in a real-world setting. However, the finding that greater engagement with EMAs was not associated with higher odds of cessation, and in fact appeared to have a chilling effect, was unexpected. One possible explanation for this finding is that incentivizing EMA participation outside the context of a clinical trial may fundamentally alter the way that users interact with the app. For example, it is possible that knowing that EMA completion was incentivized resulted in participants focusing exclusively on completing the required task rather than engaging freely with the content or other supportive features available within the application. It is also possible that participants in the incentivized arm had a self-perception of lower commitment to quitting if the incentivization was needed to promote app use. Therefore, the impact of incentivizing EMA completion on cessation outcomes could vary depending on what it is adding qualitatively to an individual's cessation process (e.g., mood support vs. tracking cravings). People likely need to use a combination of features to help them quit; therefore, more research is needed on the extent to which incentivizing certain app features impacts engagement with other app features and to quantify the impact of complex patterns of feature use (incentivized or not) on cessation. Overall, these results provide preliminary evidence that within a publicly available app, allowing autonomy with use of app features versus directed app use may result in better outcomes.

While this study provides important real-world data on EMA participation, the results cannot be generalized to all cessation applications using EMA. This is because interventions using this feature may vary in the purpose of including EMA and therefore how an EMA protocol is implemented. For example, in Businelle et al., the EMA component lasted for five weeks and data collected from the EMA was used in a Just-In-Time intervention to prevent relapse.[18] In Bricker et al., reporting

repeated cessation success in a daily EMA unlocked additional intervention content.[37] EMA protocols also differ in what they measure (e.g., cravings vs. mood). Additionally, there are differences in if/how information entered during EMA completion is presented back to participants for tracking, self-monitoring, or reflection. In quitSTART, users can track money saved by not smoking, number of EMAs completed, reports of cravings, and slips and mood reported outside of the EMAs; they are unable to view the information collected during each EMA, which may inherently limit the impact of EMA completion on tracking and self-monitoring. However, quitSTART users who complete more EMAs receive more frequent tailored messages to their responses at the time of each completion. Future research is needed to understand the optimal way in which to implement EMA functionality in research and real-world settings, which will likely depend on the expected impact of EMA completion on cessation.

Limitations

This study has several limitations that need to be considered. First, we were powered to detect a difference in smoking abstinence of at least 25% between groups for cessation rates at 27% or higher. While we successfully recruited the sample needed to reach this goal, and response rates were high, cessation rates were lower than estimated. Therefore, our power may have been reduced to determine the impact of incentivization on short-term cessation. Second, this study only examined short term (two- and four-week) cessation; however, early cessation success is predictive of longer-term success.[21,51–53] Therefore, our results pertaining to the impact of EMA completion on early cessation are still relevant to those who are interested in developing successful cessation apps. Our study also includes notable strengths. Particularly, we recruited from the Smokfree.gov Initiative web and mobile platforms; thus, our sample draws from real people who smoke who are interested in using digital tools for cessation support.[41] Lastly, this study contributes to the growing literature around smartphone app supported cessation using a widely used, publicly available program. This study highlights how user data derived from interactions with real-world cessation apps can inform

future research on the potential population health impact of these programs, as well as inform stakeholders who are engaged in program planning, design and implementation.

Conclusions

This study attempted to isolate and examine the effect of incentivizing EMA engagement on smoking cessation success for adults who smoke using a smartphone application to quit. Our findings suggest that there is no additional short-term cessation benefit conferred by incentivizing EMA completions. Future studies are needed to continue to identify smartphone app features that are the most supportive of quit attempts, and the efficacy of EMA participation for cessation among specific user groups.

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Conflicts of Interest

The authors have no conflicts of interest to declare.

Supplemental Table 1. Tailored content based on EMA responses.

If response is…	Then…	Example Tailored Content
"Happy" or "Relaxed" and Craving < 5	Happy content	Spread joy: Feeling good today? Spread happiness with those around you. One small kindness to another person can change the whole day.
"Angry", "Stressed", or "Sad" and Craving < 5	Mood content	Stress is…stressful, but your quit is too. It's important not to let it wear you down. Take control! Flex your strength but take care of you – get a glass of water, exercise.
"Happy" or "Relaxed" and Craving >= 5	Craving content	Starve your craving: Don't feed a craving by smoking! Starve it. Every time you resist the urge to smoke, your craving gets weaker, so stick to your smokefree plan.
"Angry", "Stressed", or "Sad" and Craving >= 5	Random selection of mood or craving content	Tailored mood or craving content as described above.

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