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Short Communication

Acceptability of heart rate-based remote monitoring of smoking status

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ABSTRACT

Introduction: Digital interventions present a scalable solution to overcome barriers to smoking cessation treatment, and changes in resting heart rate (HR) may offer a viable option for monitoring smoking status remotely. The goal of this study was to explore the acceptability of using smartphone cameras and activity trackers to measure heart rate for use in a smoking cessation intervention.

Methods: Participants (N=410), most of whom identified as female (75.8 %) with mean age 38.3 years (SD 11.4), were recruited via the Smoke Free app. They rated the perceived comfort, convenience, and likelihood of using smartphone cameras and wrist-worn devices for HR monitoring as an objective measure of smoking abstinence. Wilcoxon signed-rank tests and Kruskal-Wallis tests assessed differences in acceptability across device types and whether the participant owned an activity tracker/smartwatch or smartphone.

Results: Participants reported high levels of acceptability for both HR monitoring methods, with activity trackers/smartwatches rated more favorably in terms of comfort, convenience, and likelihood of use compared to smartphone cameras. Participants indicated a statistically significantly greater likelihood of using the activity tracker/smartwatch over the smartphone camera. Participants viewed the activity tracker/smartwatch as more acceptable than the smartphone camera (87.0% vs 50.0%).

Conclusions: HR monitoring via smartphone cameras and wrist-worn devices was deemed acceptable among people interested in quitting smoking. Wrist-worn devices, in particular, were preferred, suggesting their potential as a scalable, user-friendly method for remotely monitoring smoking status. These findings support the need for further exploration and implementation of HR monitoring technology in smoking cessation research and interventions.

1. Introduction

Tobacco use, despite its associated health risks, remains highly prevalent, with 47.1 million adults in the United States regularly using tobacco products (Cornelius et al., 2022; Kondo et al., 2019; Reitsma et al., 2021). In 2020, 53.9 % of people who reported smoking attempted to quit within the past year; however, only 8.5 % succeeded (Centers for Disease Control and Prevention, 2022). Interventions can more than double the likelihood of quitting, but barriers to smoking treatment include a lack of awareness of treatment options, the inability to physically access them, and insufficient insurance coverage (Husten, 2010; World Health Organization, 2021). Remote treatments, such as those delivered through smartphone applications, can reach larger groups of people with fewer barriers, as 85 % of US adults own smartphones (Pew Research Center, 2021; Whittaker et al., 2019).

Hundreds of such smoking cessation applications are available, but more research must be done to establish which ones are most effective (Whittaker et al., 2019). One difficulty of research and implementation of remote applications is the objective measurement of smoking status. Objective biological verification methods provide an unbiased way to measure smoking and typically include measuring exhaled breath carbon monoxide levels or blood, saliva, or urine-based nicotine metabolites such as cotinine or tobacco alkaloids (Benowitz et al., 2020; Thrul et al., 2023). However, these methods can be difficult for remote interventions when in-person contact is needed (e.g., urine-based), require special supplies and/or equipment, and often involve complex testing procedures (Vilardaga et al., 2023). Low sample return rates and the often prohibitive cost of test kits and devices have resulted in many researchers choosing not to include biochemical verification (Bricker et al., 2020; Thrul et al., 2023). Therefore, it is imperative to identify and

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implement objective measures of smoking that are socially acceptable, accurate, and feasible to collect remotely.

A novel approach to remote measurement involves evaluating changes in resting heart rate. Resting heart rate (HR) is known to decline within 24 h of smoking abstinence, with an average decrease ranging from 5 to 15 beats per minute (Linneberg et al., 2015; West & Russell, 1987). HR also experiences a rapid increase with the consumption of even a single cigarette, a pattern consistently observed in most individuals who smoke (Linneberg et al., 2015; Perkins et al., 1989).

Commercially available smartphone apps for smoking cessation do not currently collect objective abstinence measures, with few exceptions (Vilardaga et al., 2019; Marler et al., 2020). Yet, smartphones can employ low-cost applications that use the device's camera to detect an individual's heartbeat, offering a reliable, remote measure of HR (Coppetti et al., 2017; Heathers, 2013). Wearable activity trackers (e.g., Fitbit, Apple, Garmin smartwatches) can also passively measure resting HR. Preliminary studies suggest that monitoring HR through smartphone camera applications or activity trackers is a valid approach to detecting smoking and assessing abstinence (Cole et al., 2021; Herbec et al., 2020). Using these devices to monitor HR presents researchers with an objective measure that potentially minimizes the barriers associated with more invasive verification approaches.

Despite the promising nature of these HR monitoring methods, there is limited research on the acceptability of end-users using smartphone camera access and/or activity trackers to measure smoking. Investigating participants' preferences may contribute to addressing low verification completion rates in smoking research. Therefore, the primary objective of this study was to assess the acceptability and device ownership of smartphone camera-based HR monitoring and activity tracker HR monitoring for evaluating smoking status.

2. Methods

2.1. Participants

Participants were recruited as part of a larger study described elsewhere (White et al., 2023; White et al., 2024). All procedures were approved by the University of California San Francisco's Institutional Review Board (19-29335). Participants had to be 18 years or older, report smoking at least one cigarette per day, have plans to quit smoking within the next 7 days, speak English, currently live in the United States, and have downloaded and opened the Smoke Free application (app) on their smartphone that was used as part of the larger study. Smoke Free follows the National Centre for Smoking Cessation and Training (NCSCT) standard treatment program and is one of the most downloaded smoking cessation apps in the Apple and Android stores (Crane et al., 2019). Participants were recruited from the general user population of the Smoke Free smartphone app and were asked to participate in the research study during their initial interaction with the application. An on-screen message displayed a link to a screening questionnaire in Qualtrics and eligible participants completed a consent form.

2.2. Measures

The research team developed a baseline measure that evaluated the acceptability of different approaches to HR monitoring to verify smoking abstinence. For the smartphone method, participants were told, "One way to measure heart rate is through the camera lens on a smartphone device. To do this, you would place your finger on the camera lens for 5 min, while sitting still, to measure your resting heart rate." For the wrist-worn method, participants were told, "Another way to measure heart rate is through wrist-worn devices like a watch or an activity tracker (such as Fitbit, Apple Watch). To do this, you would have to wear the device on your wrist continuously throughout the day and night, and it would automatically track your resting heart rate.".

Across eight questions, participants were asked to rate their (a) willingness, (b) perceived comfort, (c) convenience, and (d) acceptability of using either (1) a camera lens on a smartphone or (2) a wearable wrist device to measure their HR. Each question used a 10-point rating scale (1 = "Not at all" and 10 = "Very Much"). Participants indicated via a checkbox if they owned the following: "an activity tracker like Fitbit," "a smartwatch," or "neither." Participants also answered questions regarding their attitudes toward using activity trackers and the perceived usefulness of HR monitoring to help them during a quit smoking attempt, using a three-option multiple choice format ("yes," "no," "don't know"). Other measures included in the baseline questionnaire for the full study (White et al., 2024) are beyond the scope of the current study.

2.3. Procedures

Participants received an email link to complete a baseline questionnaire in Qualtrics immediately after completing a screening questionnaire and consenting to participate in the study. The screening questionnaire consisted of demographic information questions including race, ethnicity, age, and gender. Questions about smoking were also included in the screening and baseline questionnaires such as quit smoking goals, frequency of smoking, and acceptability of using a smartphone camera as well as a wrist-worn activity tracker to measure HR. Participants received $20 compensation for completing the baseline questionnaire.

2.4. Analysis

To analyze the data, we first tallied and summarized measures of acceptability for each device type (i.e., smartphone camera & activity tracker). This involved collating participants' responses regarding their willingness, comfort, and perceived convenience of using each device. Preliminary analysis of the data used a Shapiro-Wilk test and revealed a non-normal distribution for each of the variables (comfort and convenience of using both devices and likelihood of use). Thus, Wilcoxon signed-rank tests were used to assess differences in acceptability. The Kruskal-Wallis test was also used to assess differences in participants' ratings (willingness, comfort, and perceived convenience) across device ownership categories (smartwatch, activity tracker, both, neither). Significant differences indicated by the Kruskal-Wallis were further analyzed using the Mann-Whitney *U* test to examine pairwise comparisons between different ownership categories for each rated variable.

3. Results

3.1. Sample characteristics

Participants (N=410) had a mean age of 38.3 years (SD 11.4, range 18–72 years). The majority of participants identified as female (75.8 %), followed by male (22.9 %), and a smaller number identified as non-binary/non-conforming (0.7 %), and transgender (0.5 %). Most participants identified as non-Hispanic White (80.5 %), followed by non-Hispanic Black or African American (7.8 %), mixed racial backgrounds, including combinations of White with Black or African American, American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander (10.7 %), and Asian American (1.5 %). Participants reported a range of household income levels: less than $40,000 (39.3 %), between $40,000 and $80,000 (33.4 %), and more than $80,000 (27.3 %). Participants reported a mean daily cigarette consumption of 15.5 cigarettes (SD 7.4) and a mean duration of smoking of 20.4 years (SD 12.1).

3.2. Acceptability of heart-rate monitoring methods

Fig. 1 shows the acceptability of each device type for HR monitoring, based on ratings of willingness to use, convenience, and comfort. The

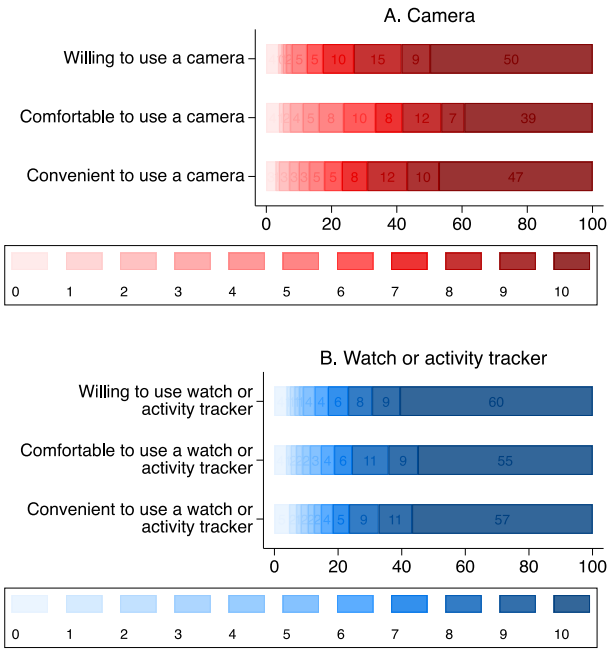

Fig. 1. Willingness to use, comfort, and convenience of devices for heart rate monitoring. Note: Inset labels indicate the percentage of participants selecting that option.

activity tracker/smartwatch, compared to the smartphone camera, was rated as significantly more comfortable (mean 8.3; SD 2.7 vs. mean 7.4; SD 2.9; $p < 0.001$, Cliff's Delta (d) = -0.192) and more convenient (mean 8.3; SD 2.9 vs. mean 8.0; SD 2.7; $p = 0.02$, Cliff's Delta (d) = -0.100). Participants indicated a slight but significantly higher likelihood of using the activity tracker/smartwatch (mean 8.5; SD 2.6) over the smartphone camera (mean 8.2; SD 2.5; $p = 0.03$, Cliff's Delta (d) = -0.096). Lastly, they viewed the activity tracker/smartwatch as more acceptable than the smartphone camera (87.0 % vs 50.0 %, Fig. 2).

3.3. Device ownership

About half of participants (53.4 %) reported that they did not own a smartwatch or activity tracker. Among those who owned a device, 33.4 % reported owning a smartwatch, 10.2 % owned an activity tracker, and 2.9 % reported owning both devices. These groups achieved significant differences in perceptions of activity tracker comfort, likelihood of use for HR monitoring, and convenience. Participants who owned an activity tracker, whether alone or with a smartwatch, rated higher levels of comfort for the activity tracker (mean 9.3, SD 1.5 vs. mean 7.4, SD 3.1; $p < 0.001$), likelihood of use (mean 9.4, SD 1.5 vs. mean 7.7, SD 3.1; $p < 0.001$), and convenience (mean 9.3, SD 1.5 vs. mean 7.3, SD 3.3; $p < 0.001$) compared to those who owned neither device.

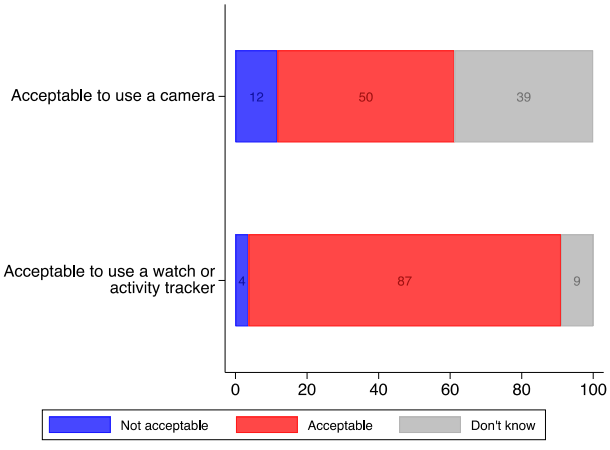

Fig. 2. Acceptability of devices for heart rate monitoring. Note: Inset labels indicate the percentage of participants selecting that option.

4. Discussion

This study evaluated the acceptability of using activity trackers or smartphone cameras for monitoring smoking status via resting heart rate among individuals interested in quitting smoking. Participants were asked to evaluate their willingness to use either an activity tracker or smartphone camera, considering factors such as comfort, convenience, and overall acceptability. The findings indicated an overall positive response from participants regarding both methods, receiving high ratings of participants' willingness to use them, comfort, and convenience.

Although both devices have promise as practical options, a larger proportion of participants preferred the activity tracker to a smartphone camera, particularly among individuals who already owned an activity tracker. Although participants were not asked the reasons for their preference, one potential factor is the requirement to sit for 5 min with the smartphone camera, compared with the more passive monitoring with activity trackers. This difference may have contributed to the camera being perceived as less convenient and contributed to its lower acceptability. Future research may explore differences in acceptability based on shorter durations and how this might impact the validity of the measure.

These outcomes suggest that HR monitoring has promise as a tool for determining smoking status. Activity trackers and smartphone cameras offer significant advantages over traditional verification methods, particularly because they are more accessible and less invasive than other approaches. With 85 % of Americans reportedly owning a smartphone in 2021, and 45 % of Americans currently owning an activity tracker, the ubiquity of wearable and mobile technology suggests that this approach would be highly scalable (DeMarco, 2022; Pew Research Center, 2021). Additionally, 7 in 10 (69 %) Americans report that they would wear a fitness tracker if their health insurance provider would cover a portion of the cost (DeMarco, 2022). Finally, this approach could be extended to monitoring the use of other substances that are shown to reliably impact HR (e.g., nicotine vaping, stimulants). However, the effectiveness of these devices for measuring abstinence is not yet established, and researchers will need to conduct large-scale validation studies. Further research on the kinetics of nicotine absorption as it relates to heart rate is also warranted (Herbec et al., 2020).

Three limitations are worth noting. First, participants were always presented with questions related to the smartphone camera first. Differences in ratings between the two modalities may have been influenced by an order effect. Second, our instructions for the smartphone camera approach suggested that the participants would need to hold their finger on the camera for the entire 5-minute duration. Sitting for 5 min is required to ensure that resting HR is collected, but holding the finger on the camera for that duration is not necessary, and this miscommunication may have impacted acceptability ratings. Third, generality of the results is limited because of the biased sample of predominantly white, female, and middle-income participants. Although the digital divide is narrowing, there continue to exist disparities in access to mobile technology that could limit access for some populations (Pew Research Center, 2021).

Nevertheless, these findings contribute valuable insights into the acceptability of using activity trackers and smartphone cameras for monitoring smoking status. This is the first study to evaluate the acceptability of using these devices to monitor heart rate to verify abstinence. Although both devices were rated highly, activity trackers were somewhat more acceptable, possibly because of their relatively greater convenience due to passive monitoring. This research highlights

the potential of leveraging technology to improve smoking cessation initiatives, presenting a scalable and user-friendly approach in contrast to traditional verification methodologies that are worthy of exploration and implementation.

Author disclosures

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Contributors: Mitnick wrote a substantial portion of the original draft and conducted analyses; Goodwin assisted with writing the initial draft and assisted with data analyses; Bubna assisted in writing a portion of the original draft; White was the Principal Investigator on the parent project, provided funding for this research, helped to conceptualize the research design, assisted with data analysis, visualization, and revisions of the manuscript; Raiff helped to conceptualize the research design and assisted with writing the manuscript.

CRediT authorship contribution statement

Matthew Mitnick: Writing – original draft, Formal analysis. **Shelby Goodwin:** Writing – original draft, Formal analysis. **Mikaela Bubna:** Writing – original draft. **Justin S. White:** Writing – review & editing, Visualization, Funding acquisition, Data curation, Conceptualization. **Bethany R. Raiff:** Writing – review & editing, Supervision, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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