



Proof-of-concept testing of a mobile application-delivered mindfulness exercise for emotional eaters: RAIN delivered as a step-by-step image sequence

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Background: Over fifty percent of individuals with overweight and obesity are emotional eaters. Emotional eating can be theorized as a conditioned response to eat for reasons that are not associated with physiological hunger. We conducted this proof-of-concept study to gather evidence that a mobile app that delivers a common non-meditative mindfulness exercise called RAIN, in a step-by-step image sequence can improve emotional eating and other outcomes over a 3-week period.

Methods: Forty-nine Canadian adults who self reported as emotional eaters (mean age =30.7 years) were recruited through social media and participated in a workshop in which RAIN and its use on the app were introduced. Participants were asked to use the app every time that they experienced a non-homeostatic craving to eat for three weeks. Emotional eating, reactivity to food cravings, perceived loss of control around food, distress tolerance, and eating-specific mindfulness were assessed pre- and post-intervention.

Results: Improvements on all outcomes were found (r-range, -0.58 to -0.28). The feasibility of the mobile application was demonstrated by a low attrition rate (8%), high user satisfaction, and strong app engagement metrics.

Conclusions: The data provide proof-of-concept evidence that a mobile app that delivers a mindfulness exercise in a step-by-step image sequence has potential to be effective and thus identifies a new approach that may reduce emotional eating in an accessible and affordable manner.

Keywords: Mindfulness; mobile applications; metaphor; eating behaviour

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Introduction

Emotional eating

More than half of Canadians live with overweight or obesity (1). Obesity is the leading cause of preventable disease in North America (2) and over fifty percent of individuals with overweight and obesity are emotional eaters (3,4). Emotional eating is the tendency to eat in response to negative affective states (5). When under emotional distress, emotional eaters are more likely to consume highly palatable that are high in fat and/or sugar (6), the regular consumption of which has been shown to modify brain mechanisms related to reward and pleasure (6-9). By consistently overconsuming sugar-laden foods, emotional eaters may be conditioning themselves to feel positive affective states when eating or seeing highly palatable foods (10). Over time, these food cues may activate learned associations (habit loops) that prompt non-homeostatic eating (11-13). In other words, emotional eating is theorized to be a reward-based eating behavior that is supported by operant conditioning and associative learning networks (14-16). For instance, if an individual consumes a highly palatable food (e.g., ice cream) and feels satisfied, they form a learned association between their emotional state (satisfaction) and their behavior (eating). Similarly, if an individual consumes a certain food (e.g., ice cream) that reduces their emotional distress, they may form a learned association between eating certain foods

and reducing emotional discomfort (17-19). According to operant conditioning, the tendency to emotionally eat is thus reinforced through the receipt of rewards (e.g., eating something tasty-positive reinforcement) and/or the elimination of unpleasant stimuli (e.g., removing feelings of stress-negative reinforcement) (20,21). Thus, to weaken this learned response, an emotional eater needs to develop the capacity to not react to their learned associations to eat tasty when experiencing emotional discomfort.

Mindfulness and emotional eating

Mindfulness is one tool that may be effective in attenuating the reward-based conditioned responses that reinforce emotional eating. Mindfulness is comprised of two fundamental components: “Attention”, paying attention to moment-to-moment experiences; and “Attitude”, maintaining an attitude of acceptance and non-judgmental curiosity towards these experiences (22,23). According to Brewer and colleagues (10), mindfulness’ “bare awareness” can apply to various processes in the reward-based habit loops of emotional eating. For emotional eating, a negative emotion can prompt a non-homeostatic craving or urge to eat. In this situation, the emotional eater has two options: either respond to their non-homeostatic craving by eating, thus reinforcing their conditioned reward-based response, or resist their non-homeostatic craving to eat and respond to this urge by not eating. A mindfulness exercise could facilitate the latter choice by fostering an individual’s ability to observe their craving states without reaction thus allowing the behavior (emotional eating) to subside over time.

Highlight box

Key findings

- Consistent use of a targeted non-meditation mindfulness exercise (RAIN) via an app can significantly reduce emotional eating.

What is known and what is new?

- Recent mobile apps have been developed to target emotional eating behaviors. However, many have not been developed in accordance with behavioral change science and their efficacy is poorly understood.
- This study is the first of its kind to develop and test the preliminary efficacy of a mobile app to reduce emotional eating by targeting the reward-based conditioned response that is theorized to maintain this behavior.

What is the implication, and what should change now?

- This data provides proof-of-concept evidence that a mobile app that delivers a mindfulness exercise in a step-by-step image sequence has potential to be effective and thus identifies a new approach that may reduce emotional eating in an accessible and affordable manner.

Using a mindfulness exercise to weaken reward-based habit loops

RAIN is a non-meditation mindfulness exercise that can be integrated into daily life to support the non-judgmental observation of uncomfortable emotions and experiences without reacting (24,25). When experiencing emotional discomfort, individuals practicing RAIN are encouraged to pause and turn their attention inwards while following the acronym’s four steps: *Recognize* what is happening; *Allow* the experience to be there, just as it is; *Investigate* with interest and care; *Non-identify* with the experience so that your self-concept is not defined by or fused with your thoughts or emotions. This exercise, in conjunction with similar mindfulness exercises, has shown to be effective for reducing emotional reactivity (26,27) and may thus be suitable for

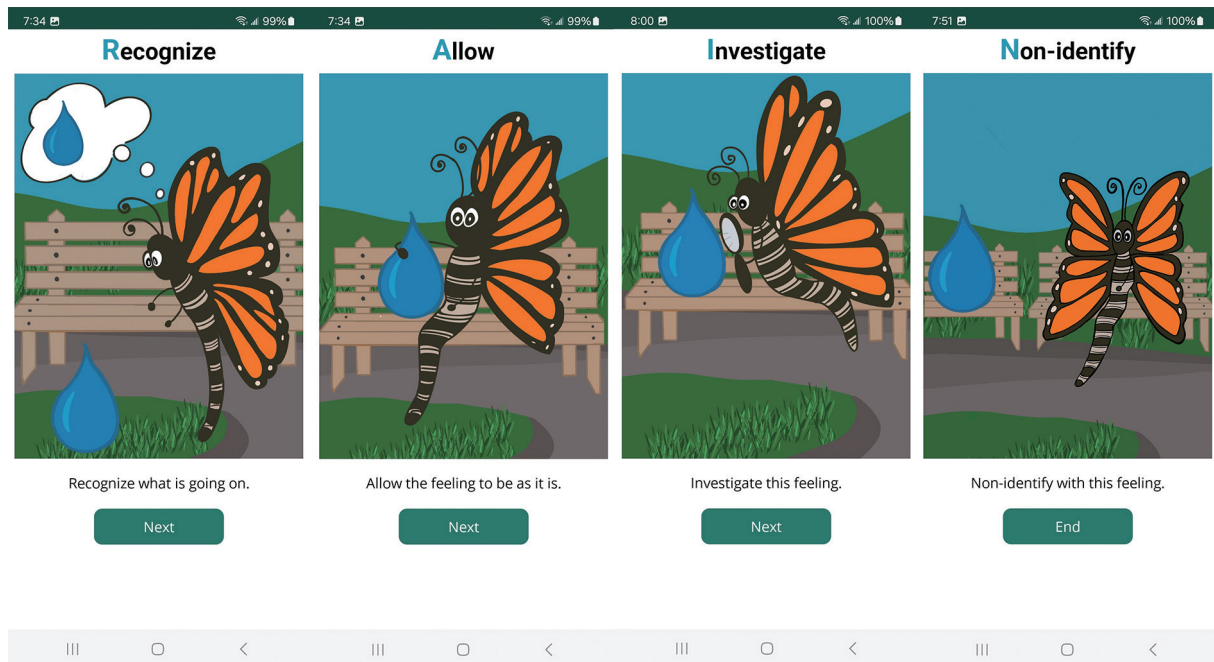


Figure 1 RAIN in-app step-by-step image sequence.

reducing emotional eating. Specifically, by practicing RAIN, emotional eaters may increase their ability to non-judgmentally observe their craving states instead of reacting to them by eating, thus reducing their learned association to eat when experiencing emotional discomfort (10,28).

Mobile health-assisted applications for behavior change

Smartphone applications have shown efficacy as a novel, feasible, and cost-effective method to assist with behavior modification (29,30). The use of mobile health-assisted applications (hereinafter referred to as “apps”) is particularly promising considering the increased demand for remote access to healthcare interventions which would allow for greater accessibility to care and the potential for scalability (31,32). Recently, several mobile apps have been developed to support weight loss (33,34) reductions in emotional eating (35-37). A recent meta-analysis points to the promising efficacy of using smartphone application-based interventions for weight loss (38). Although these apps have shown preliminary effectiveness, many were not developed in accordance with evidence-based theories of behavioral change (39). Additionally, the existing apps tend to rely heavily on large amounts of psychoeducation and exercises are delivered as lengthy text or audio files.

These various features and components that accompany these mobile apps can inevitably create challenges for both researchers and participants alike. Too many elements and large amounts of information may burden users, thus affecting their engagement with the app and the apps’ effectiveness and may create challenges in elucidating the active ingredients that support changes in emotional eating. To address these challenges, our app provides users with only the four steps of the RAIN exercise. These four steps are introduced to the user as an image sequence where each step is illustrated and accompanied by a keyword and phrase (see *Figure 1*). Whereas there are existing mobile apps that target weight reduction and maintenance or emotional eating behaviors, to our knowledge, no mobile application has yet been developed to reduce emotional eating by specifically targeting the reward-based conditioned responses that maintains this behavior through the explicit and consistent practice of one particular exercise, such as RAIN.

Study aim

The purpose of this proof-of-concept study was to test a mobile application delivered evidence-based mindfulness exercise (RAIN) using a step-by-step image sequence to reduce emotional eating. Specifically, the study’s aim was to explore

whether consistent use of a targeted mindfulness exercise (RAIN) when experiencing a non-homeostatic craving to eat would weaken the reward-based conditioned response of emotional eating and reduce the behavior over time.

We hypothesized that the consistent use of this targeted mindfulness exercise when experiencing a non-homeostatic craving to eat would significantly reduce participants' emotional eating, perceived frequency and intensity of food cravings, loss of control over eating, behavioral reactivity to negative mood states, and significantly increase participants' non-reactivity around food and food-related environments, as well as their non-judgment towards their eating-related emotions and thoughts. Our primary outcome was to assess the acceptability and feasibility of the app in reducing emotional eating. All other outcomes were exploratory in nature.

Methods

Recruitment and procedure

Participants were recruited between June and September 2022 via social media (e.g., Facebook, and Reddit) and email listservs. The present study was approved by McGill University's Research Ethics Board (REB-II; #PJT-156324). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). All participants provided informed consent prior to participation. Participants who expressed interest were sent a pre-screening questionnaire to assess their eligibility. This survey assessed the participants' current level of emotional eating, perceived distress towards their emotional eating, and internal motivation for changing their emotional eating behavior. Study eligibility criteria were: (I) being at least 18 years of age; (II) residing in Canada; (III) owning a smartphone and willing to download the mobile application that delivered RAIN; and (IV) English literacy. Participants were excluded if they were (I) pregnant in the past 6 months; (II) currently undergoing cancer treatment; (III) using medication that affects body weight or appetite; (IV) self-reported an eating disorder; (V) scoring less than 3.5 on a measure of emotional eating; (VI) indicating no intrinsic motivation to change their emotional eating; and (VII) demonstrating minimal distress by their emotional eating behavior. Intrinsic motivation was assessed by asking the participants to rate the extent to which they were motivated to change their emotional eating on a scale of 1 (not motivated) to 10 (very motivated). Only participants with scores greater than or equivalent to 8 were included in

the study.

After completing the pre-screening questionnaire, eligible participants were sent a consent form and a baseline questionnaire. The baseline questionnaire included all study measures and a socio-demographic questionnaire. Upon completion, participants were invited to join a 1-hour virtual group workshop facilitated by a senior clinical psychology PhD candidate. A maximum of five participants were scheduled per workshop. The workshop included psychoeducation on operant conditioning and how it relates to reward-based eating behaviors (see [Appendix 1](#)). During this training session, participants were introduced to the mindfulness exercise (i.e., RAIN) using the mobile app and provided with information on how this targeted mindfulness training may help reduce conditioned responses to eat for non-homeostatic reasons. Participants were encouraged to use the RAIN exercise via the app whenever they experienced a non-homeostatic craving (urge) to eat over a 3-week period. At the end of each week, participants were sent a weekly questionnaire and were asked to send the research team their app engagement data. No further training sessions or virtual discussions took place across the 3-week period. Following the end of the intervention, participants were asked to complete the post-program questionnaire and were compensated up to 50 Canadian dollars contingent on the frequency of completed questionnaires.

Measures

Socio-demographic questionnaire

Study participants were asked to report their age, gender, racial/ethnic background, highest level of education, and occupation. All demographic information can be found in [Table 1](#).

Food Craving Questionnaire-T-r (FCQ-T-r) (40)

The FCQ-T-r measures the frequency and intensity of food cravings in general. The 15-item scale assesses five dimensions of craving experiences: lack of control over eating, thoughts or preoccupation with food, intentions and plans to consume food, emotions before and during food cravings, as well as cues that may trigger food cravings. Items were rated on a scale of 1 (never) to 6 (always). Sample items include: "I feel like I have food on my mind all the time", "I crave foods when I feel bored, angry or sad" and "If I am craving something, thoughts of eating consume me". Pre- and post-study Cronbach alphas for the

Table 1 Demographic of participants

Variable	N (%)
Gender	
Man	25 (51.0)
Woman	24 (49.0)
Age, years	
19–29	28 (57.1)
30–39	13 (26.5)
40–49	5 (10.2)
50–59	2 (4.1)
60 or older	1 (2.0)
Racial/ethnic background	
African	4 (8.2)
African-Caribbean	10 (20.4)
East or South Asian	10 (20.4)
European	4 (8.2)
Latin, Central, or North American	5 (10.2)
Middle Eastern	1 (2.0)
Other	6 (12.2)
Unknown	9 (18.4)
Education	
High school diploma or equivalent	1 (2.0)
Some college/university	10 (20.4)
Bachelor’s degree	21 (42.9)
Graduate degree	8 (16.3)
Unknown	9 (18.4)
Employment status	
Employed	28 (57.1)
Student	6 (12.2)
Retired	1 (2.0)
Self-employed	4 (8.2)
Unable to work	1 (2.0)
Unknown	9 (18.4)

Table 1 (continued)

Table 1 (continued)

Variable	N (%)
Income	
\$20,000 or less	2 (4.1)
Between \$20,001–\$40,000	4 (8.2)
Between \$40,001–\$60,000	7 (14.3)
Between \$60,001–\$80,000	9 (18.4)
Between \$80,001–\$100,000	2 (4.1)
Between \$100,001–\$120,000	9 (18.4)
More than \$120,000	3 (6.1)
Prefer not to answer	4 (8.2)
Unknown	9 (18.4)
Previous mindfulness experience	
Yes	12 (24.5)
No	25 (51.0)
No response	3 (6.1)
Unknown	9 (18.4)

cravings, restrained eating, eating disorder symptoms, and impulsivity (41).

Dutch Eating Behaviour Questionnaire (DEBQ) (5)

The DEBQ is a 33-item self-report measure that assesses three dimensions of eating behaviours: emotional eating, restrained eating, and external eating. Individuals are asked to indicate the extent to which they agree with each statement from 1 (seldom) to 5 (very often). Only the emotional eating subscale was used for this study. The subscale includes items such as: “Do you have a desire to eat when you are anxious, worried or tense?”. Pre- and post-study Cronbach alphas for the present study were between 0.79 and 0.96. The validity of the DEBQ subscales have been shown (5), and more recently, its ecological validity has been established (42).

Brief Loss of Control Over-Eating Scale (LOCES-B) (43)

The LOCES-B is a 7-item measure that assesses an individual’s self-reported tendency to lose control over their eating behaviors. Items on the scale are rated from 1 (never) to 5 (always). Sample items include: “I felt like my cravings to eat overpowered me” and “I found myself eating despite negative consequences”. Pre- and post-study

present study were 0.94 and 0.96. The FCQ-T-r construct validity has been established in previous research through correlations with related constructs, such as specific food

Cronbach alphas for the present study were 0.93 and 0.94. Significant correlations with related measures, including eating disturbances, general distress, functional impairment, and general self-control, provide support for its convergent validity with related constructs (43).

The Short UPPS-P Impulsive Behavior Scale (SUPPS-P) (44)

The SUPPS-P negative urgency scale is a 4-item subscale of the UPPS-P that assesses an individual's tendency to act rashly in response to negative mood states. Items on the scale are rated from 1 (I strongly disagree) to 4 (I strongly agree). Higher scores represent greater levels of impulsivity. Sample items include: "When I feel bad, I will often do things I later regret in order to make myself feel better now". Pre- and post-study Cronbach alphas for the present study were 0.81 and 0.89. The scale has demonstrated good external validity in previous studies (45-48).

Four Facet Mindful Eating Scale (FFaMES) (49)

The FFaMES is a 29-item self-report measure that assesses four dimensions of eating-specific mindfulness: non-reactance, non-judgment, external awareness, and internal awareness. Individuals are asked to indicate the extent to which they agree with each statement from 1 (never) to 5 (very often), with higher scores indicating greater eating-specific mindfulness. Sample items include: "I get carried away by my thoughts when I eat" and "I notice how the smell of food makes me want to eat". Pre- and post-study Cronbach alphas for the present study ranged between 0.81 and 0.95. The scale has demonstrated preliminary convergent and divergent validity (49).

Cognitive Fusion Questionnaire-Food Cravings (CFQ-FC) (50)

The CFQ-FC is a 7-item scale that assesses cognitive fusion with undesirable thoughts regarding food cravings and urges to eat. Items are rated from 1 (never true) to 7 (very true), with higher scores indicating greater cognitive fusion. Sample items include: "It's very hard for me to let go of my food urges or cravings even when I know that letting go would be very helpful" and "I struggle to control my food urges or cravings". Pre- and post-study Cronbach alphas were 0.93 and 0.94. The scale has demonstrated good convergent and divergent validity, being positively associated with similar constructs, indicators of eating, and general psychopathology (50).

Power of Food Scale (PFS) (51)

The PFS is a 15-item questionnaire that assesses three different features of hedonic hunger in relation to the proximity of palatable food: reactions to palatable food being widely available in the general environment, reactions to palatable food that is present but not yet tasted, and reactions to palatable food when first tasted but not yet consumed. Items are rated from 1 (do not agree at all) to 5 (strongly agree), with higher scores indicating greater hedonic hunger. Sample items include: "I get more pleasure from eating than I do from almost anything else" and "Just before I taste a favorite food, I feel intense anticipation". Pre- and post-study Cronbach alphas were 0.96. Findings have supported the convergent validity of the PFS, with positive correlations with measures of disinhibition, external eating, and binge eating (51), as well as its ecological validity (52).

Intensity of daily food cravings

Each time that a participant used the app they were prompted to rate their perceived food craving intensity on a scale of 1 (low) to 10 (high) before starting the RAIN exercise, and immediately following completion of the RAIN exercise.

Daily mobile application engagement data

Participants' daily frequency and duration of app use was recorded throughout the study. These recordings, intended to be used as an objective measure of mindfulness practice time, were collected by the mobile application, and stored locally on the participants' smartphones. Participants were asked to send the research assistant these data at the end of each week.

App acceptability and usefulness

Upon completion of the study, participants were asked to rate several aspects of app acceptability and usefulness for reducing emotional eating and food craving intensity on a rating scale from a 1 (strongly disagree) to 7 (strongly agree). To interpret the results, we categorized scores of 1, 2, 3 as "disagree", 4 as "neutral" and 5, 6, 7 as "agree". Items include: "The IluviaX app met my overall needs", "The IluviaX app helped me control my emotional eating", "The IluviaX app helped me ride out my cravings to eat", "I would continue using the IluviaX app in my daily life", "I would recommend the IluviaX app to a friend". All items of the app acceptability and usefulness questionnaire are provided in [Appendix 1](#). Additionally, an open-text option was also provided to allow for specific feedback and general

Table 2 Pre- and post-intervention scores in outcome variables for study participants

Variable	Pre-intervention (n=49)	Post-intervention (n=45)	P value	Effect size (r)
FCQ-T-r	5.27±1.07	3.27±1.77	<0.001	-0.56
DEBQ-EE	4.38±1.27	3.00±1.58	<0.001	-0.57
LOCES-B	4.57±1.07	2.71±1.57	<0.001	-0.56
SUPPS-P-NU	2.75±1.00	2.38±1.00	<0.01	-0.32
FFaMES-NR	1.67±0.56	2.67±1.44	<0.001	-0.55
FFaMES-NJ	1.88±1.09	2.63±1.25	<0.001	-0.52
FFaMES-EA	4.17±1.00	3.50±1.00	<0.001	-0.46
FFaMES-IA	4.00±1.50	3.33±1.17	0.019	-0.28
CFQ-FC	4.50±2.14	3.85±1.79	<0.001	-0.41
PFS	4.53±1.67	3.40±1.37	<0.001	-0.58

Due to violations of normality a Wilcoxon sign-ranked test was used to compare pre- and post-intervention changes across outcome variables. Values are reported as median ± IQR due to this violation of normality. FCQ-T-r, Food Craving Questionnaire-Trait-revised; DEBQ-EE, Dutch Eating Behaviour Questionnaire-Emotional Eating subscale; LOCES-B, Brief Loss of Control Over-Eating Scale; SUPPS-P-NU, Short UPPS-P Impulsive Behavior Scale-Negative Urgency subscale; FFaMES-NR, Four Facet Mindful Eating Scale-Non-Reactance subscale; FFaMES-NJ, Four Facet Mindful Eating Scale-Non-Judgment subscale; FFaMES-EA, Four Facet Mindful Eating Scale-External Awareness subscale; FFaMES-IA, Four Facet Mindful Eating Scale-Internal Awareness subscale; CFQ-FC, Cognitive Fusion Questionnaire-Food Cravings; PFS, Power of Food Scale; IQR, interquartile range.

comments about the mobile application. A qualitative content analysis (53) was applied to the open-ended feedback to analyze the participants experiences with the app.

Statistical analyses

Continuous outcome variables were tested for normality with the Shapiro-Wilk test. Due to violations of normality, a Wilcoxon sign-ranked test was used to compare pre- and post-intervention changes across outcome variables. The median and interquartile range (IQR) of all outcome variables are reported in *Table 2*. Spearman correlations were used to determine whether the frequency and duration of practice was associated with changes in outcome variables. Statistical analyses were performed in IBM SPSS Statistics (IBM SPSS Statistics for Windows, Version 27.0) with $P < 0.05$ considered statistically significant.

Results

A total of 66 participants were recruited for the study. Forty-nine participants (25 men and 24 women) consented to the study and attended the workshop. The 17 remaining participants did not fulfil the study's eligibility requirements. Namely, these participants were either not

from Canada or did not demonstrate adequate intrinsic motivation to change their emotional eating. Participants' ages ranged from 19 to 62, with a mean age of 30.7 years [standard deviation (SD) =8.87 years]. There was large diversity with regards to racial/ethnic background: 28.6% African or African-Caribbean, 20.4% East or South Asian, 10.2% Latin, Central, or North American, 8.2% European, and 2.0% Middle Eastern. Of the participants, 59.2% had attended university, 65.3% were currently employed, and 51% did not have prior experience with mindfulness. All demographic information can be found in *Table 1*.

Of the 49 enrolled participants, 45 (91.84%) completed the 3-week intervention. Non-completers, as defined as those who did not complete the post-questionnaire, used the app an average of 8.7 times, with each session lasting an average of 50.56 seconds. No statistically significant differences were found in the baseline and sociodemographic questionnaire between completers and non-completers. All 49 enrolled participants were included in the analyses. As expected, participants significantly reduced their emotional eating (DEBQ-EE; $P < 0.001$), frequency and intensity of food cravings (FCQ-T-r; $P < 0.001$), loss of control over their eating (PFS; $P < 0.001$), and their tendency to act rashly in response to negative mood states (Negative Urgency subscale) (SUPPS-P-NU;

Table 3 Spearman correlation coefficients of pre- and post-intervention change scores in outcome variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. FCQ-T-r	1.00															
2. DEBQ-EE	0.75**	1.00														
3. DEBQ-RE	-0.43*	-0.23	1.00													
4. DEBQ-EX	0.84**	0.81**	-0.25	1.00												
5. LOCES-B	0.88**	0.66**	-0.29	0.77**	1.00											
6. SUPPS-P-NU	0.002	0.12	0.23	0.15	0.05	1.00										
7. FFaMES-NR	-0.89**	-0.83**	0.26	-0.86**	-0.85**	-0.10	1.00									
8. FFaMES-NJ	-0.52**	-0.62**	-0.03	-0.56**	-0.57**	-0.13	0.65**	1.00								
9. FFaMES-EA	0.70**	0.79**	-0.18	0.83**	0.64**	0.03	-0.84**	-0.60**	1.00							
10. FFaMES-IA	0.27	0.38*	0.02	0.49**	0.28	-0.24	-0.47**	-0.34*	0.63**	1.00						
11. CFQ-FC	0.47**	0.41*	0.04	0.42*	0.56**	0.28	-0.45**	-0.30	0.33	-0.03	1.00					
12. PFS	0.82**	0.80**	-0.18	0.87**	0.73**	-0.02	-0.91**	-0.62**	0.83**	0.38*	0.47**	1.00				
13. Avg CR	-0.12	0.10	0.17	-0.14	-0.24	-0.23	-0.001	-0.19	-0.03	0.15	-0.17	0.008	1.00			
14. Sess frequ	-0.02	-0.02	0.05	-0.17	-0.09	-0.30*	0.08	0.02	-0.06	-0.09	0.08	0.05	0.53**	1.00		
15. Sess tot time	-0.34	-0.06	0.45**	-0.22	-0.12	-0.45**	0.13	-0.07	0.003	0.34	-0.12	0.14	0.53**	0.65**	1.00	
16. Sess av time	-0.32	0.002	0.54**	-0.03	0.01	-0.35*	0.01	-0.20	0.12	0.43*	-0.13	0.25	0.26	0.10	0.76**	1.00

Change scores were created by subtracting the participants baseline scores from their post-intervention scores. Due to violations of normality, Spearman's rank correlation coefficients were used. Pre-intervention data are collected for 49 participants and post-intervention data are collected for 45 participants. *, $P \leq 0.05$; **, $P \leq 0.01$. FCQ-T-r, Food Craving Questionnaire-Trait-revised; DEBQ-EE, Dutch Eating Behaviour Questionnaire-Emotional Eating subscale; DEBQ-RE, Dutch Eating Behaviour Questionnaire-Restrained Eating subscale; DEBQ-EX, Dutch Eating Behaviour Questionnaire-External Eating subscale; LOCES-B, Brief Loss of Control Over-Eating Scale; SUPPS-P-NU, Short-form Negative Urgency Scale; FFaMES-NR, Four Facet Mindful Eating Scale-Non-Reactance subscale; FFaMES-NJ, Four Facet Mindful Eating Scale-Non-Judgment subscale; FFaMES-EA, Four Facet Mindful Eating Scale-External Awareness subscale; FFaMES-IA, Four Facet Mindful Eating Scale-Internal Awareness subscale; CFQ-FC, Cognitive Fusion Questionnaire-Food Cravings; PFS, Power of Food Scale; Avg CR, average craving reduction; Sess frequ, session frequency (the number of times that the participants used the app); Sess tot time, total time spent on app in seconds; Sess av time, average time spent on app in seconds.

$P < 0.01$). Participants also significantly increased their non-reactivity around food and food-related environments (Non-Reactance subscale) (FFaMES-NR; $P < 0.001$) as well as their non-judgment towards their eating-related emotions and thoughts (Non-Judgment subscale) (FFaMES-NJ; $P < 0.001$). Food craving intensity decreased an average of 3.39 points (range, 0 to 7.45 points) immediately following the RAIN exercise. Participants used the app an average of 19.11 times (SD = 14.46 times) across the 3-week intervention period with a range of 2 to 56 times. The average duration of each in-app session was 86.36 seconds with a range of 6 to 1,261 seconds (21.02 minutes). The total average length of use was 26.13 minutes with a range of 21 seconds to 293 minutes. Total session time and frequency of app use were significantly associated with average reductions in food craving intensity following the RAIN exercise ($P < 0.01$) as

well as a reduction in impulsivity towards negative mood states as measured by the SUPPS-P-NU ($P < 0.01$). Emotional eating and other study outcomes were significantly reduced from pre- to post-intervention (Table 2). However, change scores were not correlated to the total duration of session use and frequency of app use. All correlations of outcome variables can be found in Table 3.

App acceptability and usefulness

The app was well-received by most participants; of the 48 participants who provided feedback, 95.9% agreed that it was easy to use, 70.8% agreed that the app was useful, 75.0% agreed that it helped control their emotional eating, 72.9% agreed that it helped control their cravings to eat, and 83.3% agreed that they would recommend it to a friend.

Table 4 Qualitative content analysis of open-ended feedback

Themes	Example quotes of themes	Number of participants that endorsed the themes
Positive		
The instructions in the app are easy to follow	“Go at your own pace” “Easy to follow the steps”	5
The instructions in the app are easy to understand	“The app is easy to understand” “It’s self-explanatory”	7
The app is easy/simple to use	“It was easy to use” “Very easy to use”	30
The app is easy to implement because it is quick	“The app is quite convenient and brief” “Doesn’t waste time at all”	6
The app helped	“It helped me a lot with my cravings” “It helped me reflect and become more aware of my feelings surrounding the cravings”	18
Negative		
The app would benefit from using reminders	“Having to remember to use it” “There should be notification[s] so that users won’t forget”	9
The app would benefit from adding more instructions	“I wish there were a bit more instructions in each step” “More text on each screen about what to do at each step”	9
The app would benefit from using more interactive features	“I wish it was a bit more interactive” “Allow the user more of an interactive experience”	9
The app would benefit from including personalization features	“The [...] app didn’t use features that will allow me to personalize my information on it” “Adding a calendar to track the cravings of the users”	6

The open-ended feedback was categorized into positive and negative themes using a content analysis. Comments categorized under the positive theme include: (I) that the app instructions were easy to follow and to understand; (II) that the app was easy/simple to use; (III) that the app was easy to implement as it was brief; (IV) and that the app helped participants. Comments categorized under the negative theme include: (I) suggestions for the inclusion of text reminders; (II) more instructions, as well as (III) greater interactive and personalized features. Participant feedback and frequency of participants who endorsed positive and negative themes are provided in *Table 4*.

Discussion

We conducted this proof-of-concept study to gather evidence

that a mobile app that delivers a common mindfulness exercise, RAIN, in a step-by-step image sequence has the potential to improve outcomes over a 3-week period. Results showed significant improvements across all outcome variables with small to medium effects. Specifically, our app demonstrated a significant decrease in emotional eating with medium effects that are comparable to other mindfulness-based interventions for emotional eating (54). Moreover, significant decreases in the frequency and intensity of food cravings were also found. Participants additionally reported a reduction in their loss of control around eating, along with less impulsivity when experiencing negative emotions. Likewise, participants showed significant increases in their non-reactance to food and food-related environments as well as non-judgment towards eating-related emotions and thoughts. The feasibility of the mobile application was

demonstrated by low attrition rates.

Approximately ninety-two percent of participants completed the 3-week intervention. This engagement rate is higher than previous smartphone interventions that have targeted disordered eating behaviors (55-57). One factor that may explain these high engagement rates is the simplicity of the app and the ease with which it could be effortlessly integrated into daily life. Indeed, in written feedback, many participants reported the app's simplicity and usability as particularly helpful for reducing their emotional eating. This high adherence contrasts with many in-person interventions for emotional eating that tend to have higher dropout rates [e.g., (58-61)]. Together, these findings provide preliminary support for the use of simple image-based illustrations delivered by a mobile app to promote behavior change. The acceptability of the targeted mindfulness mobile app was demonstrated by high ratings of its usefulness and helpfulness. Overall, participants found the mobile application easy to use and beneficial for reducing their emotional eating and controlling their cravings to eat. Many participants also reported that they would recommend this app to a friend. Qualitative written feedback also provided evidence for the app's acceptability with themes including overall satisfaction and a perception that the intervention was effective in reducing emotional eating. Overall, participants appeared satisfied with the design of the app and found the app easy to integrate into their daily lives. These results are in line with the app's engagement data, which showed that participants used the app an average of 19.11 times across the 3-week program. Several suggestions were also made for improving the mobile application, which included wanting more personalized and interactive features, and reminders or prompts to use the app more often. These recommendations will be incorporated into the next phase of our mobile app development, which aims to provide users with a range of both mindfulness and Acceptance and Commitment Therapy (ACT) (62) exercises and metaphors that will be delivered through step-by-step image sequences. Although ACT incorporates mindfulness principles similar to RAIN, it additionally encourages clients to make behavioural choices that are concurrent with their core values (62). Both mindfulness and ACT-based therapies have shown preliminary efficacy in reducing emotional eating (54,63-65).

Although the session length and frequency of app use was not associated with reductions in emotional eating in this proof-of-concept study, greater use of the RAIN exercise was significantly associated with greater reductions

in impulsivity towards negative mood states. This result is notable as it implies a potential dose-response relationship that targets a key mechanism of the reward-based conditioned response of emotional eating. Specifically, one of the first steps to managing emotional eating is to learn to not react (i.e., not eat) in response to negative emotions. Our results allude to skill acquisition of non-reactivity and the utility of the app-delivered RAIN exercise in targeting a key mechanism of change. Moreover, the significant small association between practice effects and reductions in perceived craving intensity following the RAIN exercise is also noteworthy as it alludes to the feasibility of using an app to target specific mechanisms, such as non-reactivity, that support behaviour change. Moreover, this is the first study to our knowledge that provides empirical evidence for the efficacy of RAIN as a standalone treatment for emotional eating.

Limitations

The present study has several limitations. Firstly, the study sample may not accurately reflect all individuals who emotionally eat given that we pre-screened to include only those who were distressed by their emotional eating and motivated to change their emotional eating. However, this targeted approach aligns with the population in which interventions can have a significant impact. Moreover, a diagnosis of an eating disorder could not be entirely excluded as participants were only asked to self-report if they have been diagnosed with an eating disorder. The relatively small sample size employed in this study raises concerns about the generalizability of the findings. A larger participant pool would enhance the external validity of the results and would allow for more robust conclusions. Additionally, the absence of a control group in the study design hinders the ability to conclusively attribute observed improvements solely to the intervention. The recruitment method, primarily via social media, introduces a potential selection bias, as it may attract individuals who are already predisposed to technology or possess a specific interest in mindfulness, thereby limiting the broader applicability of the findings. Moreover, providing the participants with a 1-hour pre-study workshop may have influenced the strength of the findings. Future research should consider assessing the effectiveness of target-mindfulness apps in the absence of a psychoeducational supplement. A strength of the current study was that the sample consisted equally of men and women, addressing the common issue of women

being overrepresented in studies of eating behaviors and disorders (66), and that the sample included a wide range of racial/ethnic groups. While craving intensity was measured immediately before and after the RAIN exercise, other outcome variables such as emotional eating were only assessed before and after the treatment intervention. Consequently, the retrospective self-reports might be biased. Future research could consider incorporating more objective measures or real-time assessments to mitigate this limitation and provide a more reliable and sensitive assessment of behavior change.

Conclusions

Our study provides proof-of-concept evidence that an app that targets the reward-based conditioned responses of emotional eating through an image based step-by-step mindfulness exercise can reduce emotional eating, and that the approach is feasible and acceptable. This proof-of-concept study provides the groundwork for a randomized controlled pilot and feasibility study in preparation of a randomized controlled trial to study the effectiveness of the app. This work may draw attention to the importance of simplicity and usability in mHealth app development for behavior change.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The present study was approved by McGill University's Research Ethics Board (REB-II; #PJT-156324). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). All participants provided informed consent prior to participation.

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