



Exploring the theoretical pathways through which asthma app features can promote adolescent self-management

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Abstract

Asthma apps often lack strong theoretical underpinnings. We describe how specific features of asthma apps influenced adolescents' self-observation, self-judgment, and self-reactions, which are key constructs of Self-Regulation Theory (SRT). Adolescents (ages 12–16) with persistent asthma ($n = 20$) used two asthma self-management apps over a 1-week period. During semi-structured interviews, participants identified their asthma goals and the app features that best promoted self-observation, self-judgment, and fostered positive self-reactions. Interviews were digitally recorded, transcribed verbatim, and analyzed thematically using MAXQDA. Adolescents' goals were to reduce the impact of asthma on their lives. Adolescents reported that self-check quizzes, reminders, and charting features increased their ability to self-observe and self-judge their asthma, which, in turn, helped them feel more confident they could manage their asthma independently and keep their asthma well-controlled. Asthma apps can positively influence adolescents' self-management behaviors via increased self-observation, self-judgment, and increased self-efficacy.

Keywords

Adolescent, Asthma, Self-management, App, mHealth, Self-Regulation Theory

INTRODUCTION

Nearly 1 in 10 children under the age of 18 have asthma, making it the most common chronic condition among youth in the USA [1, 2]. Asthma negatively impacts the quality of life of young people in several domains [3] and causes more than 10 million days of school absences and over half a million emergency department visits each year [4]. Poorly controlled asthma limits the ability of young people to engage in daily activities [5, 6]. Adolescents, in particular, may experience age-related difficulties as they assume responsibility for self-management tasks from their parents and process feelings of being different from their peers [7, 8].

The negative impacts of asthma are largely preventable if adolescents engage in self-management behaviors [9–11], including symptom prevention (e.g.,

Implications

Practice: Health care providers should consider recommending apps as self-management tools for adolescents with asthma since apps can enhance adolescents' self-management behaviors through increased self-observation, self-judgment, and self-efficacy.

Policy: Newly developed apps should be targeted to adolescents and adhere to evidence-based asthma guidelines.

Research: Large-scale trials with a representative sample of adolescents with asthma should be conducted to evaluate whether apps increase self-management behaviors sufficiently in order to positively influence clinical outcomes.

Electronic supplementary material

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treatment adherence, trigger avoidance), symptom monitoring, acute symptom management (e.g., bronchodilator use), and communication with important others (e.g., health care providers, family members, peers) [12]. Unfortunately, adolescents often do not optimally self-manage their asthma. For example, controller medication adherence rates are generally low for youth, ranging from 50 to 70 % [13–15]. Additionally, asthma-related communication between young people and their providers is often limited to just a few questions and frequently does not meet national guidelines [16–19].

Although the National Asthma Education and Prevention Program (NAEPP) expert panel recommends that every asthma intervention address self-management behaviors [20], many asthma apps do not include self-management features [21, 22]. In a recent review of 147 asthma apps, Huckvale and colleagues concluded that even though the number of asthma apps more than doubled between 2011 and 2013, newer apps were not more likely than older

apps to satisfy evidence-based recommendations for information content and design of self-management tools [22]. Additionally, rigorous evaluations of the effects of asthma self-management apps are sparse. Qualitative data suggest that mobile phone-based asthma monitoring features positively impact several adolescent outcomes, including better symptom and trigger awareness, increased self-efficacy, and improved asthma self-management and medication adherence [23, 24]. A 2013 Cochrane Review was only able to locate two randomized controlled trials (RCTs) of asthma self-management apps and findings as to whether apps improve clinical outcomes are mixed [25]. A trial of adolescents and adults with asthma conducted by Ryan et al. [26] found that the use of a mobile phone intervention based on asthma management clinical guidelines did not significantly improve asthma control compared with paper-based monitoring. The second trial of adults with asthma found that a mobile-based self-care intervention improved quality of life, peak flow rate, exacerbation and emergency visits, and medication adherence rates compared to the control group [27]. Given the variability in findings, the authors of the Cochrane review recommended that future evaluations of app-based interventions should use theoretical constructs to inform app development in order to facilitate the ability of researchers to tease out the relative contribution of each app feature on patient outcomes. However, developing app features that truly operationalize a theory's constructs remains an underdeveloped area of research and most mobile adherence and disease management interventions do not report a guiding theoretical framework [28, 29], including internet-based asthma self-management interventions [30].

Self-regulation theory (SRT) (Fig. 1) may help elucidate the pathways through which features of asthma self-management apps affect adolescent self-management behaviors [31, 32]. SRT explains the ways in which several intrapersonal and external factors affect an individual's use of disease management strategies to achieve personal goals and improve physical functioning [31–33]. Three behaviors are at the core of the theory: self-observation, self-judgment, and self-reaction. *Self-observation* involves explicit attempts to observe or monitor one's own behavior (e.g., an adolescent keeps an asthma diary to observe and document symptoms). *Self-judgment* occurs when an individual uses criteria to assess an asthma-related situation or problem (e.g., an adolescent determines the severity of lung restriction by evaluating a peak flow reading). Lastly, *self-reaction* is an individual's responses to self-observations and self-judgments. The two most important self-reactions are outcome expectations, for example, whether the adolescent believes a disease management strategy, such as taking controller medication, helps him/her achieve an expected outcome or goal, and self-efficacy, or whether the adolescent is confident he/she can perform a specific self-management behavior.

Young people prefer technology-based education [7, 34]. In fact, adolescents with asthma have indicated

that they are most interested in receiving asthma information and communicating with their doctors using e-mail and text messages [34]. Because adolescents prefer to receive asthma education through e-mail or text messages [34], a mobile asthma self-management app may hold greater interest for adolescents than traditional face-to-face asthma interventions. Additionally, rates of adolescent smartphone ownership are steadily increasing (over 73 % of teens (ages 13–17) currently have access to a smartphone) [35]. Despite adolescents' preference for and use of technology, only 8 of 147 asthma apps target children or young adults [22]. Of these eight apps, only four have self-management features, such as features to document and chart symptoms, peak flows, and triggers [22]. Only two apps included medication reminder features to help young people adhere to their medication regimens. Moreover, detailed information on the theoretical underpinnings of these apps has not been reported.

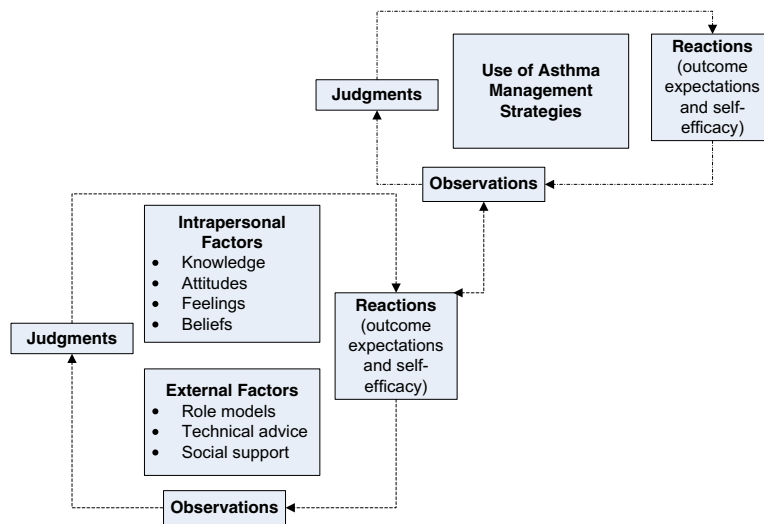
Our purpose is to evaluate the strengths and weaknesses of two existing asthma apps and develop recommendations for a comprehensive, theoretically based, asthma self-management app for adolescents. We specifically evaluate how app features promote self-observation, self-judgment, and foster positive self-reactions and then outline how app features, as posited by SRT, could work synchronously to increase adolescents' asthma self-management and improve asthma outcomes.

METHODS

Study population

A convenience sample of 20 adolescents and their caregivers were recruited between 2013 and 2014 from two pediatric practices located in an urban area of North Carolina. The pediatric practices were members of the *North Carolina Child Health Research Network*, which is a practice-based research network. At both practices, a designated clinic liaison used the electronic health record to identify potentially eligible adolescents with asthma and told their families about the study prior to their regularly scheduled clinic appointment. When they arrived for their appointment, families were made aware of the study research assistant (RA), who was present in the clinic's waiting room.

Interested families who approached the RA were screened for eligibility. Adolescents were eligible if they: (1) were 12–16 years of age; (2) were able to read and understand English; (3) owned a cell phone, smartphone, or tablet; (4) were present at the visit with an adult caregiver (biological parent or legal guardian); and (5) had persistent asthma. Persistent asthma was defined as experiencing asthma-related daytime symptoms more than twice a week, asthma-related nighttime symptoms more than twice a month, or receiving one or more long-term control therapies for asthma [20, 36]. Caregivers were eligible if they: (1) were at least 18 years of age, (2) could read and understand English, and (3) were the adolescent's biological parent or legal guardian.



Legend: How self-observation, self-judgement, self-reactions, intrapersonal factors, and external factors collectively influence the use of asthma management strategies

Fig 1 | The self-regulation process in disease management

Study Procedures

The RA obtained informed assent and consent from eligible adolescents and caregivers, respectively, and then asked them to separately complete a brief demographic survey before their regularly scheduled medical visit. After their medical visit, the RA gave the adolescent an iPod Touch that contained two asthma self-management apps; one app was targeted to adults and one was targeted to children. The two apps were purposively selected from those that were available on the iOS platform in late 2012 because they had the combined characteristics of being user-friendly and having multiple self-management features. Because, at the time, no app was targeted to adolescents, we selected one app that was targeted to adults and one app that was targeted to younger children.

Table 1 describes the various self-management features that were available on the apps. The RA demonstrated how to use the two apps and then allowed participants to explore the apps on their own for approximately 10 min. The adolescents then completed a 20–30-min semi-structured interview that included two close-ended questions about adolescents' technology use. These two questions are the only data included in this paper from these in-person semi-structured interviews. Adolescents were asked about their initial impressions of the apps including ease of use, perceived usefulness, and suggestions for improvement. Participants were then asked to use both apps over the course of the next week. The RA did not indicate how much time they should spend using the app or prompt participants to use the app during that time. Approximately 1 week later, adolescents completed a 20–30-min telephone interview (interview guides are included as [supplementary materials](#)). Adolescents were asked questions on usefulness of the apps including how the apps would help them better monitor or

control their asthma, specific app features, and how they would use the apps to communicate with and obtain support from others. Both the in-person and telephone interview were digitally audio-recorded. Adolescents were allowed to keep their iPod Touches as incentives. The study was reviewed and approved by the University of North Carolina Institutional Review Board and was conducted in accordance with the tenets of the Declaration of Helsinki.

Measures

Demographic and clinical characteristics—Adolescents reported their gender, age, and ethnicity (Hispanic, Latino, or Spanish origin). Race was measured as a categorical variable (White, Black or African-American, American Indian or Alaskan Native, Asian, Native Hawaiian and Other Pacific Islander, or Other) and, for descriptive purposes, was recoded into the following categories: non-Hispanic White, Black, Hispanic, and Other. Adolescents indicated their grade in school, asthma disease duration (in years), and perceived asthma severity, ranging from 1 = *very serious* to 4 = *not at all serious*. Caregivers reported their annual household income (<\$25,000, \$25,000 to \$34,999, \$35,000 to \$49,999, \$50,000 to \$74,999, and >\$75,000).

Technology use—Adolescents answered close-ended questions during the first interview to report: how often they use the Internet (once or more a day, a few times a week, a few times a month, hardly ever, or never) and whether they used a cell phone (yes/no), owned a cell phone (yes/no), or owned another Internet-capable device (such as a computer, tablet, or iPad) (yes/no). Using a yes/no response format, we also asked adolescents if they had: (1) ever looked up something about their health on the Internet; (2)

Table 1 | Description of self-management features from the child and adult asthma app

Feature	Description	Adult or Child App
Peak flow monitoring	An electronic form where one can enter their daily peak flow measurements. The information can be relayed to chart and visualized in graphical format	Adult
Trigger and symptom tracking	Separate forms for selecting triggers and symptoms experienced each day. The information can be viewed as a list in the Chart/Diary feature	Adult
Diary/notes	Blank form for adding notes that are saved as daily entries	Adult and Child
Chart	Provides an overview of daily peak flow measurements, symptoms, and triggers. Symptoms and triggers are displayed in a list view while peak flow measurements can be displayed in a chart view	Adult
Doctor report	Allows user to email a report with information from the Chart feature to his/her provider	Adult
Medication reminder	Alerts user when it is time to take their medications. Allows users to drag and drop the medication into the open mouth of a monster to verify that medication has been taken	Child
Self-check	A series of questions that assess asthma control and outputs a numerical score telling the user how well-controlled their asthma is	Child
Doctor appointment reminder	A form where you can input the date of your doctor's appointments and receive a reminder	Child
School form	Physician approval forms that allow students to possess and use an inhaler in school. Form can be emailed and printed but cannot be filled out in the app	Child
My allergies and emergency plan	A place to document allergies, allergy medication, emergency medications, allergic reaction plan, peak flow records, emergency contact, and doctor's phone number.	Child

ever downloaded an app to a cell phone, tablet, or other handheld device; (3) ever paid to download an app; (4) ever downloaded a health-related app; (5) ever used an asthma app before the study; or (6) ever avoided downloading an app due to privacy concerns. Adolescents also reported if they had ever sought asthma-related information online.

Perceived usefulness of app features—Adolescents rated the usefulness of the various app features, including peak flow monitoring, asthma triggers, charts and graphs, an asthma diary, doctor reports, medication reminders, school forms, allergy and emergency plan, doctor appointment reminders, and asthma self-check quizzes (Table 1). Usefulness ratings ranged from 1 = *not at all useful* to 5 = *very useful*. We dichotomized this response so that answers of 3 and above were categorized as useful and answers of 1 or 2 were categorized as not useful. Participants also answered open-ended questions about the features they used most and least often.

Analytical Approach

Descriptive statistics were calculated to characterize the study sample. Frequencies were used to examine adolescents' perceptions of the usefulness of app features. Each interview was transcribed verbatim, deidentified, and analyzed using MaxQDA software (Berlin, Germany). Framework synthesis [37, 38] based on

framework analysis [39, 40] was used to analyze the data. Initial transcript interviews were independently read and coded by three research team members in order to identify relevant themes and create a codebook with definitions and example quotations that was applied to all transcripts [41]. The codebook included codes for app features, self-management behaviors, and other important issues raised by study participants [37]. After the codebook was finalized, a primary coder coded all interview transcripts and a secondary coder coded 10 % of the transcripts; intercoder reliability was good ($k=0.85$). After all coding was complete, a fourth research team member worked with the primary and secondary coders to explore how app features were related to the SRT constructs of self-observation, self-judgment, and self-reactions.

RESULTS

Sample characteristics and adolescent technology use

Table 2 presents the demographic and clinical characteristics of adolescents, and Table 3 summarizes their technology use. Four adolescents did not complete their 1-week telephone interview; three of these adolescents were female, two were White, and two were Black. The mean age of adolescents who dropped out was 14.5 years, which was almost identical to those who completed the study. Of note, no adolescents had used an asthma app prior to enrolling in the study.

Table 2 | Demographic characteristics of adolescents

Adolescents (<i>n</i> = 20)	<i>N</i> (%) or Mean ± SD
Age in years (range 12–17)	14.7 ± 1.6
Female	9 (45)
Race	
White	9 (45)
Black	8 (40)
Other	3 (15)
Ethnicity	
Hispanic, Latino or Spanish origin	4 (20)
Non-Hispanic	16 (80)
Grade in school (range 6–11)	8.3 ± 1.6
Years with asthma (range 1–16)	9.9 ± 4.8
Perceived asthma severity (range 1–4)	2.4 ± 0.9
Caregiver-reported annual household income ^a	
<\$25,000	7 (35)
\$25,000 to \$34,999	3 (15)
\$35,000 to \$49,999	2 (10)
\$50,000 to \$74,999	2 (10)
>\$75,000	4 (20)

^a Two caregivers chose not to answer this question

Asthma goals

Adolescents' asthma-related goals ranged from controlling or managing asthma (*n* = 5), not having symptoms (*n* = 4), getting off medications (*n* = 3), not having asthma (*n* = 3), and helping others to be better organized (*n* = 1). One participant noted his goal was to make asthma “disappear.” The following quotations summarize adolescents' goals in their own words.

As I get older I want, um, I want to get off more medications and, um, cause I don't

Table 3 | Adolescent technology use

Variable	Number (%)
Frequency of internet use	
More than once a day	10 (50)
Almost every day	7 (35)
A few times a week	3 (15)
Uses a cell phone	17 (85)
Owens a cell phone	17 (75)
Owens an Internet-capable device (e.g., computer, tablet)	19 (95)
Ever downloaded an app	20 (100)
Ever downloaded a health-related app	3 (15)
Ever paid to download an app	11 (55)
Ever avoided downloading an app due to privacy concerns	8 (40)
Ever used an asthma app prior to the current study ^a	0
Ever used the Internet to look up health-related information ^a	16 (100)
Ever used the Internet to look up asthma information ^a	10 (63)

^a Only the 16 adolescents who completed the 1-week follow-up interview answered these questions

want to be taking so many medications as I do now, and I want my asthma to slowly get better and better so that it just goes away, so I don't have to worry about taking so many medications and stuff.

Eventually I'd like to be able to get to where I have no trouble with asthma, uh, where I can play sports, I can go hang out or run around and hang with friends or whatever and not worry about my asthma holding me back from anything.

Reminder features

Seven (44 %) participants found the appointment reminder feature helpful and nine (56 %) found the medication reminder feature helpful. Medication reminders were cited as the most used feature by six (38 %) adolescents. Reminders helped adolescents with forgetfulness and helped them become more observant of their medication-taking behaviors. In other words, adolescents linked these features to increased self-observation. For example, one adolescent stated:

And I always remember to take my medicine easier with this app so I think that will help out. Because if I could continue to take my medication on sort of, uh, a consistent flow it makes it easier. And so over time, I think it will help me control my asthma.

Another participant stated that the reminder made “taking your medicine a little bit fun.” Others noted how reminders improved knowledge of medications because, to set up a reminder, individuals need to know which medications are rescue medications and which ones are control medications.

Peak flow monitoring feature

Although 8 participants (50 %) rated the peak flow monitoring feature as useful, more than a third (38 %) of adolescents cited this as the feature they used least often. One adolescent stated that the app caused her to start using her peak flow meter even though she never used it before. Participants also reported using the peak flow graphics to better self-judge their asthma. In one adolescent's words,

Like it—it really did help me out, um, and to know about the progress of my—of my asthma... it let me like know more of how my asthma was going during the weeks and—and days.

Diary feature

Although 11 (69 %) adolescents reported that the diary feature was useful, only one stated that the diary was the feature that she used most. The convenience of

being able to document information electronically and track progress over time were cited as benefits of this feature. One adolescent noted, “because every time I enter it at the device, I wanted to go back to see how it was, all I have to do is go to the diary and see how it’s been over a time period.” Thus, the diary was linked to increased self-judgment.

Trigger and symptom tracking feature

Twelve (75 %) participants thought the trigger and symptom tracking feature was useful, and it was cited as the most used feature by three (19 %) participants. Adolescents linked the trigger feature to increased self-observation, in that they could track their exposure to triggers over time, which led them to engage in better environmental control behaviors. For example, one adolescent noted:

The triggers, um, I thought it was good because it would help you keep track of like what triggered it before, so you would know to stay away from it or stay indoors if it’s like a certain type of plant blooming or something. And it would help you, uh, remember that for the future years, so you could, um, remember to stay away from it.

However, intrapersonal factors, such as inadequate knowledge of one’s triggers, limited some adolescents’ use of the feature, as evidenced by the following quote: “I really don’t know what my triggers are, so I really didn’t use it that much.”

Charting feature

Eleven (69 %) participants thought the charting feature was useful and 5 (31 %) cited the chart as the feature they used most. Adolescents appreciated being able to visualize how their asthma was changing over time. The charting feature seemed to increase both self-observation and self-judgment, as adolescents liked to see if their asthma was “getting better or worse.”

I liked the chart. It kind of helped me see what I was, uh, how I’ve been doing over the course of time. Um, I normally didn’t really monitor it that much, I kind of let my mom did it, and this way if I were using this, I could kind of tell myself how I was doing on my own.

The chart, cause I can like sc-, I can watch it, I can scale my asthma and I can see if it’s worse or if it’s getting better, or if it’s really serious I need to do something about it, it helps me. Um-hum.

Self-check feature

Eight (50 %) participants thought the self-check feature was useful and 6 (38 %) cited this as the feature they

used most often. This feature was helpful for increasing adolescents’ ability to self-judge their asthma severity:

I think it’s really good because you get to take this test over and over again, and like over time, maybe your score might get, your score might get higher and your score might get higher and that might be a good thing. And you’d be really – and like I like the test because you can really see if your, your asthma is getting better.

Adolescents also discussed how they were able to take action to keep their asthma under control when the self-check feature result indicated that they were having problems. For example,

I think what this is, this is very good. It helps you, um, track it so maybe you can catch your – catch it before it gets bad, you know, saying, you know, my – I wrote down I have a lot of symptoms all this week. Maybe, maybe I should, you know, check and see if I need to start doing my Xopenex and, you know, maybe do more upkeep I guess.

Allergies and emergency plan feature

Ten (63 %) participants noted that the allergy and emergency plan was useful. However, no adolescents stated this was the feature they used most often and 3 (19 %) said it was the feature they used least often. Adolescents liked having all the information about what to do in case of an emergency in one location that was easy to share with others, so they could get the support they need in case of an asthma attack. In this way, the plan was linked to both technical advice and social support. For example, one adolescent stated,

You know, you can just pull it up and say, you know, I have all the information and I have it with me. And maybe in the case of a flare, flare, really your friend can see it and say, oh, it says her emergency plan is to do this, this, and this, so I can help her do this, this, and this.

Another participant noted that this feature was not helpful since he already knew what to do in case of an emergency.

School form

Ten (63 %) participants thought the school form feature was useful. However, this was not cited as the most used feature by any participant. Adolescents liked that they could share the form with their school nurse so he or she could know what medications they were taking. Like the emergency plan, the school form seemed most linked to social support and technical advice. In the words of one adolescent,

I could give it to my school if there's a problem with my asthma, they can say, "Oh, well she did send us this document saying that she has asthma, so we need to let her take her medicine," so that's a good thing.

One adolescent noted that her school has its own medication form, so she would not be able to use the one that was included with the app.

Doctor report form

Nine (56 %) participants stated that the doctor report form was a useful feature, although none actually used the feature. Teens thought the report "travels a lot better" than paper and is a nice way to summarize their asthma experience in a concise format to give to their providers. One adolescent noted, "I think that was good...so like if your doctor just wonders how you're doing when he doesn't see you, you could, you could send him the chart and he could see how you've been doing."

External and interpersonal factors

The frequency with which adolescents' used the asthma apps varied based on a number of intrapersonal and external factors. For example, competing demands limited adolescents' ability to use the apps; one participant noted that she was too busy to use an asthma app. Additionally, adolescents who felt like they were already doing a good job managing their asthma were less likely to spend time using the apps since they did not have symptoms or triggers they wanted to document. As one adolescent stated, "Because, like my asthma is well-controlled, so like a lot of the stuff here I don't really need, but maybe like other people who have it worse will like probably need it more." Although adolescents thought electronically documenting information was convenient, other barriers could limit use of certain features, particularly the peak flow feature. One adolescent stated,

I think most people just don't want to do them [peak flows]. And you don't want to have to – because first, you have to, you know, use it. You have to use it three times and you really start coughing, hacking after you've used it. Most people don't like peak flows. And then in addition to actually having to do the peak flow, you – if you want to see how you're doing really, you have to document it.

How app features influence self-observation, self-judgment, and self-reaction

All adolescents who completed the telephone interview ($n=16$) stated that the app helped them better monitor their asthma and 15 (94 %) said that they felt more involved in managing their asthma after using the app. Thirteen (81 %) believed the app helped them

better control their asthma and 10 (63 %) stated that it helped them follow their doctor's advice better. Nine adolescents believed that the app targeted toward adults helped them the most with managing their asthma while 4 believed the app targeted toward children helped them manage their asthma most; there was no consistent pattern in responses based on age (i.e., one 13-year-old preferred the child-focused app while another 13-year-old preferred the adult-focused app).

Using a combination of self-management features is what seemed to have the strongest relationship with increasing self-observation and self-judgment among adolescents. Adolescents often noted how using features in concert with each other gave them a more holistic view of their asthma and how to manage it appropriately.

I used the symptoms, triggers, and notes, cause–because with the symptoms, it can–it pretty much tells how–like what I'm feeling at that time like throughout the day and the triggers is like if I have a flare up or, uh, an attack or–then it'll–it'll help, it'll show like what–what caused it in the notes because it just–I can just put down everything that happened throughout the whole day.

I like symptoms because I can see like, like I'm going down and, like you can go to the diary and also kind of coordinate with the triggers because like you could add a trigger and you still have trouble for like this thing, like let's say you had smoke or something, smoke was your trigger. That might like go to symptoms and see cough, wheeze, chest tightness or shortness of breath.

Using the app also resulted in several positive self-reactions for adolescents, including feeling more confident that they could take more responsibility for managing their asthma, obtaining the support they need to manage asthma, and communicating more effectively with others about their asthma. Adolescents described wanting to share data collected from the app, including peak flow, trigger, and symptom data, with their providers. In adolescents' own words:

I think it makes you feel more confident just because it makes everything like easier to get to and easier to use. And also, maybe if you have someone looking at it and, you know, they want to see your trigger, you can pull them up and say here are my triggers. You have them all there. Maybe if you forgot a medication, I know that the doctors they always ask you and I know a lot of people don't remember the doses, so they can say, oh, you know, hold on. I have the dose. I'll pull it up for you right now. It makes you seem like you have more control over it, instead of you're just part of doing what your

doctor tells you to. Although, I mean, that's very good but you seem like you have a larger part in it I guess.

It kind of keeps me to where I can see what I've done, instead of it just being in my mom or my doctor knowing how far I've come, where – if I'm getting better or worse, if I'm normal for myself or anything, I can kind of keep myself in check.

Normally it was parents doing it before, and, um, I would just, um, not keep track of it, but now that, uh, I see that there are apps out there for this sort – certain purpose, then I can do it myself and not have to rely on my parents to do it. It makes a difference because, um, it – most ki-, most teens like, you know, play on their phones and stuff, text, do stuff like that. Now that I have this, um, on a device that I can use to do those things, then I can do it like in the process while I'm doing the other things.

DISCUSSION

Adolescents described how using app features helped them engage in more asthma self-management behaviors. Some app features, such as diaries, reminders, and places to document triggers and symptoms, appeared to be associated with increased knowledge and self-observation, whereas other features, such as self-check quizzes and charts, increased participants' ability to self-judge their asthma severity. Adolescents expressed an interest in sharing app data with their family members and providers, which could foster increased communication about asthma and enhance social support to better self-manage their condition. By engaging in more self-observation and self-judgment, adolescents reported feeling more confident that they could manage their disease on their own or obtain support when needed. Interpersonal factors, such as attitudes and beliefs, influenced how often adolescents used specific app features.

Setting goals is an important aspect of SRT since the theory posits that adolescents are more likely to engage in self-management behaviors if these behaviors help them achieve their goals [32]. Neither of the two apps used in this study incorporated goal-setting. Our data suggest that adolescents' goals are to reduce the negative impact of the disease on their lives so they can engage in their usual daily activities. However, several adolescents cited goals that would be difficult or impossible to achieve, such as not having asthma. For this reason, we recommend that apps include a pre-populated list of customizable achievable asthma goals from which adolescents can choose. Giving adolescents the ability to customize these goals could

motivate app use by increasing perceived relevance of the app. For example, adolescents could customize a “have fewer symptoms” goal to “not wheeze when running.”

The trigger and symptom tracking feature was rated as one of the most useful features by participants. In addition to fostering increased self-observation by allowing adolescents to track trigger and symptom exposure, it helped some adolescents identify gaps in their trigger knowledge and to think more deeply about their triggers, which are also important outcomes of this feature. Future asthma apps could potentially further enhance trigger and symptom self-management by linking environmental data about an adolescent's personal triggers to the app, so adolescents can more proactively engage in appropriate environmental control strategies.

The medication reminder, charts, and self-check features were highly used by adolescents. Forgetting medications is a common barrier to medication adherence among adolescents [42], so reminder features are important to include in an adolescent asthma self-management app. Although neither of the apps we evaluated allowed participants to graphically view their medication use over time, including a chart that displays medication use may help adolescents identify specific days, like weekends, when they have more trouble adhering to their controller medications. Adolescents can quickly look at their charts and self-judge whether their asthma is improving or worsening over time and self-check features allow adolescents to determine whether their asthma is well-controlled. Features that provide adolescents with information about how well their asthma is controlled, however, should be based on current evidence-based recommendations as the large majority of existing asthma apps do not adhere to evidence-based guidelines [22]. Because there are several asthma control measures available, it is important to select measures that have been validated and proven reliable in an adolescent population [43].

The peak flow feature received mixed reviews. This is not surprising given that a previous study found that only about a third of youth reported having access to a peak flow meter [44]. Showing the peak flow results in graphical format seemed to facilitate adolescents' ability to self-judge their asthma severity. Because adolescents who used the feature found it extremely convenient and useful for self-observing and self-judging their asthma severity, we recommend that all adolescent asthma self-management apps include a peak flow monitoring option. For adolescents who do not use peak flow meters, an alternative symptom monitoring option should be available. Again, because there are a number of symptom monitoring diaries and questionnaires that could be used, it is important to select tools that have been validated with adolescents [43].

Several features were deemed useful by adolescents even though they did not report that these features directly contribute to increased self-observation and

self-judgment. These features included the school nurse form, the allergy and emergency plan, and doctor report. Adolescents believed these features could enhance asthma-related communication with school nurses, friends, and providers, which is an important domain of asthma self-management [12]. Because providers often ask adolescents how often they use their control and rescue medications and experience with symptoms, data collected via apps that can be displayed in an easy-to-read graphical format could potentially enhance adolescent-provider communication during office visits [45]. These data could also potentially be transmitted directly to the child's electronic health record [46].

As SRT predicts, intrapersonal and external factors appeared to influence how often adolescents used the asthma apps. As has been found in other studies [24], adolescents were less motivated to use apps when they thought their asthma was well-controlled or when they were busy. This suggests that, during those time periods, asthma apps should not demand continual interaction with the adolescent but should, rather, provide occasional cues to action to promote continued app use. Perhaps, a weekly quiz that gauges symptoms and goal achievement could be used to keep adolescents at least minimally engaged with the app during those times. Then, during times when their asthma is not well-controlled or they are not achieving their goals, the app could encourage daily interaction. Including gamification elements, such as badges or moving to a higher level, could also help overcome intrapersonal barriers to motivate adolescents to use an asthma app [30].

This study has several limitations. We recruited a small convenience sample of adolescents and, although our sample was racially diverse, the use of a convenience sample limits our ability to generalize results, especially to adolescents in rural areas who may have less access to cell phones and may also be less likely to have health insurance [47]. Participants used the two asthma apps for a 1-week period, so they had real-world experience with the apps to inform their opinions about the usefulness and effects of various features. It is possible that giving adolescents a longer period of time to use the apps would have yielded additional barriers and benefits of using asthma apps. Additionally, several participants discussed having technical difficulties with various features, which limited their ability to provide detailed information about some features' usefulness. This also points to the need for app developers to engage in extensive usability testing before releasing an app. Also, four adolescents did not complete the 1-week follow-up interview. Although those adolescents did not appear demographically different from the adolescents who completed the study, selection bias could have affected our results. For example, it is possible that more motivated adolescents or adolescents who were better self-managers were more likely to complete the follow-up interview. Last, positively-framed questions as well as social

desirability bias may have artificially inflated adolescents' ratings of the usefulness of the various app features.

The current study offers new findings regarding the theoretical pathways through which asthma self-management apps can influence adolescent self-management behaviors. We described how specific app features increased self-observation and self-judgment and how, in concert with each other, features increased adolescent self-efficacy to take ownership of managing their asthma. Given the increasing rate of adolescent cell phone ownership [35] and adolescents' preferences for using electronically based asthma self-management programs [7, 34], behavioral researchers and app developers should partner to create a self-management app geared specifically toward adolescents. We recommend that any newly developed app contain the following features: goal setting, medication reminders, symptom monitoring, trigger monitoring, asthma control self-assessment quizzes, and charting features. Additionally, the app should provide adolescents with the option to share their data with their parents and providers as this may enhance their access to social support and technical advice for improving asthma self-management.

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Compliance with Ethical Standards

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