



Contents lists available at ScienceDirect



Smartphone-based vs paper-based asthma action plans for adolescents

Tamara T. Perry, MD^{*,†}; Alexandra Marshall, PhD[‡]; Ariel Berlinski, MD^{*}; Mallikarjuna Rettiganti, PhD^{*,†}; Rita H. Brown, BS^{*,†}; Shemeka M. Randle, MS[§]; Chunqiao Luo, MS^{*,†}; Jiang Bian, PhD, MS^{||}

^{*} Department of Pediatrics, University of Arkansas for Medical Sciences, Little Rock, Arkansas

[†] Arkansas Children's Hospital Research Institute, Little Rock, Arkansas

[‡] Fay W. Boozman College of Public Health, University of Arkansas for Medical Sciences, Little Rock, Arkansas

[§] Arkansas Department of Health, Little Rock, Arkansas

^{||} Department of Health Outcomes and Policy, University of Florida, Gainesville, Florida

ARTICLE INFO

Article history:

Received for publication April 26, 2016.

Received in revised form November 22, 2016.

Accepted for publication November 29, 2016.

ABSTRACT

Background: Adolescents with asthma are at risk of poor outcomes and are traditionally difficult to reach. **Objective:** To examine adolescents' use of and asthma outcomes associated with smartphone- vs paper-based asthma action plans (AAPs).

Methods: We conducted a 6-month randomized clinical trial with adolescents (12–17 years old) with persistent asthma. Participants used their respective smartphone or paper AAPs for medication instructions and peak flow or asthma symptoms logging. AAP use was measured electronically for smartphone users and via mail-in diaries for the paper group. Changes in Asthma Control Test (ACT) and self-efficacy scores were examined.

Results: Thirty-four adolescents participated in this study (median age, 15.4 years). Participants were mostly African American (62%) with state-issued insurance (71%). Adolescents in the smartphone group accessed the AAP a median of 12.17 times per week or 4.36 days per week but only recorded medications or symptoms and peak flow data in the electronic diary a median of 10 days per month during the 6-month period. Participants in the paper group recorded data a median of 23.5 days per month on their paper diaries. Overall, there were no changes in ACT and self-efficacy scores between groups. Adolescents with uncontrolled asthma (baseline ACT score ≤ 19) had an improvement in ACT for the smartphone group (before, 11; after, 20) ($P = .04$) compared with no change in the paper group (before, 17; after, 17) ($P = .64$). Adolescent satisfaction with the application was high, with 100% stating they would recommend the smartphone AAP to a friend.

Conclusion: Adolescents were frequent and highly satisfied users of the smartphone AAP with a subset of participants with uncontrolled asthma demonstrating possible clinical benefit. Findings suggest a need for larger-scale studies to determine the effectiveness of smartphone-based AAPs among high-risk patients with asthma.

Trial Registration: clinicaltrials.gov Identifier: NCT02091869.

© 2016 American College of Allergy, Asthma & Immunology. Published by Elsevier Inc. All rights reserved.

Introduction

Asthma is a chronic relapsing respiratory disease that is responsible for significant childhood morbidity. For the past several decades, it has been recognized as an important public health issue frequently associated with pediatric acute health care use.¹ Even

Reprints: Tamara T. Perry, MD, Department of Pediatrics, Allergy and Immunology Division, University of Arkansas for Medical Sciences, 13 Children's Way, Slot 512-13, Little Rock, AR 72202; E-mail: perrytamarat@uams.edu.

Disclosures: Authors have nothing to disclose.

Funding Sources: This study was funded by the Arkansas Biosciences Institute and Arkansas Children's Research Institute.

<http://dx.doi.org/10.1016/j.anai.2016.11.028>

1081-1206/© 2016 American College of Allergy, Asthma & Immunology. Published by Elsevier Inc. All rights reserved.

when follow-up visits are conducted according to national guidelines,² day-to-day symptoms and exacerbations can go undocumented between regularly scheduled visits for children with asthma. To improve asthma self-management, asthma action plans (AAPs) are recommended for patients with asthma²; however, studies indicate that 50% of children do not receive AAPs as recommended by guidelines.³ Furthermore, real-time tracking of traditional AAP use is impossible because of their paper-based nature, and paper diaries are potentially inaccurate because of patients' ability to backfill or falsify data. A smartphone-based solution with electronic, real-time data tracking capabilities and time-stamped logging could potentially serve to eliminate

inaccuracies and errors in data logging. This solution can also lessen the burden for patients who are expected to keep up with paper-based AAPs and diaries.

Because of high morbidity and mortality rates, clinicians and researchers are compelled to continue to search for innovative and engaging methods to decrease risks for high-risk populations, such as adolescents. Adolescents are at particularly high risk for adverse asthma outcomes because of poor medication adherence, increased forgetfulness, increased risk-taking behavior, and poor self-management skills.^{4,5} Adolescents also often deal with competing priorities, such as school, friends, and work, that may interfere with optimal asthma management.⁶ Despite these risks and competing priorities, adolescents are expected to accept more responsibility for health care decision making as they transition to adulthood. Mobile technology use is ubiquitous among US adolescents⁷ and has the potential to bridge the gap in chronic disease self-management because it can be incorporated into the adolescent's daily life. Although a recent study revealed that 209 mobile applications for asthma were commercially available, most patient-directed applications offered general training and teaching or consisted of generic tracking capabilities for patients without personalization.⁸ We hypothesized that at-risk groups such as adolescents may benefit from a personalized smartphone-based AAP aimed to improve asthma self-management and health outcomes by providing individualized real-time feedback, providing asthma medication reminders, and allowing for electronic asthma diary use.

Methods

We conducted a 6-month randomized pilot study comparing AAP use rates and asthma outcomes for adolescents using smartphone- vs paper-based AAPs. Informed consent and assent were obtained from all participating caregivers and participants, respectively. All study procedures were approved by the University of Arkansas for Medical Sciences Institutional Review Board. Adolescents were recruited from outpatient clinics at Arkansas Children's Hospital by convenience sampling. Potential participants received information about the research study and contact information for the research team via recruitment flyers posted in outpatient clinics or direct contact with clinic staff at the time of a scheduled appointment. Interested participants contacted the study team or gave permission to clinic staff to be contacted by study personnel. Before enrollment, potential participants were screened to ensure that inclusion criteria were met. Inclusion criteria were (1) adolescents 12 to 17 years old with physician-diagnosed persistent asthma who had been prescribed an asthma controller within the previous 6 months and (2) access to a smartphone compatible with the application (at least iOS v8 or Android v4.1) with a data plan. Participants were enrolled in the study during the months of April to October 2014 and participated in the study for 6 consecutive months.

Each participant's current asthma medications were confirmed by medical record review and parental interview. All participants received asthma education on symptoms-based and peak flow–based asthma monitoring and proper use of AAPs. All participants received a valved holding chamber device (Aerochamber, Monaghan Medical Corporation, Plattsburgh, New York) and a peak flow meter (TruZone, Monaghan Medical Corporation, Plattsburgh, New York). Training was provided, and each participant demonstrated proper technique with both devices. Participants were then randomized to receive either the smartphone- or paper-based AAP as his/her primary self-management tool. Participants were instructed to use their respective AAP daily for routine use and as needed for managing worsening symptoms for 6 months.

The smartphone application was developed by the study team and previously pilot tested among adolescents with persistent asthma.⁹ The study team was composed of a board-certified allergist, board-certified pediatric pulmonologist, certified respiratory therapist, a health behaviorist, application developers, and community-based researchers. To ensure that the application was patient centered and tailored to fit the preferences of the target population, the smartphone application was enhanced to include colorful and teen-friendly graphics based on suggestions of community stakeholders (teens with asthma and their parents) and updated to meet requirements for current Android and iOS systems. To provide real-time tracking of use, we integrated the Piwik¹⁰ open analytics platform into the AAP smartphone application. Each critical user activity on the AAP application, such as logging in, entering peak flow, and logging out, was registered as a separate event in Piwik along with its timestamp. The smartphone application automatically timed out after 5 minutes of inactivity.

After enrollment, the application was downloaded to the smartphone of each participant randomized to the smartphone group. Features of the application included (1) personalized AAP for routine and worsening asthma symptoms; (2) daily medication reminders; (3) monthly prescription refill reminders; (4) self-management tips, such as trigger avoidance; and (5) electronic peak flow and/or symptoms diary. Smartphone participants were instructed to monitor and log peak flow and/or symptoms along with medication doses on the application both daily and as needed (during worsening symptoms). Peak flow or symptoms based monitoring was based on the preferences of the adolescent and his/her health care practitioner; participants were not required to monitor both symptoms and peak flow. Once data were entered by the participant (either peak flow or symptoms), the application automatically navigated to the participant's personalized treatment zone screen to provide instructions for medication dosing. If rescue medication dosing was recommended per the participant's yellow or red zone instructions, the participant was prompted to reassess symptoms or peak flow 20 minutes after the recommended rescue dose. Participants were prompted to contact their regular health care practitioner or seek emergency care for symptoms that failed to improve or worsened despite rescue medication dosing (Fig 1). If the participant entered severe symptoms, such as lips turning blue, trouble talking, or throat tight, the application screen immediately and automatically navigated to a shortcut prompting the participant to "Call 911/EMS" for emergency assistance. In addition to these interactive features, daily push notifications were automatically sent to remind participants to record peak flow or asthma symptoms and to take controller medications per the adolescent's personalized AAP. Delivery time of the messages and reminders were customized based on the participant's preferences (ie, before school). Educational messages were sent via push notifications twice weekly at varying times.

Certain features of the application required mobile connectivity or Wi-Fi connection, such as the initial downloading of the application; however, clinically important features of the application were accessible 24 hours per day 7 days per week without mobile connectivity or Wi-Fi connection. For example, participants were able to access their personalized AAP, enter peak flow or symptoms data, and receive real-time feedback at any time regardless of mobile connectivity. These features were programed as part of the password-protected native application on the participant's phone and required no exchange of data with the remote server to operate. For data compilation and monitoring by research personnel, participant-entered data (peak flow or symptoms) were uploaded to a secure server automatically if the participant was connected to Wi-Fi or mobile network or temporarily stored on the participant's device until the next time the participant was connected to the mobile network or Wi-Fi.

Asthma Zones	Peak flow or Symptoms	Treatment
Green Zone	Peak flow reading $\geq 80\%$ of personal best OR asthma symptoms are absent and no limitation of activities	No extra medications recommended. The participant was instructed to continue daily controller asthma medications.
Yellow Zone	Peak flow reading 51–79% of the participant's personal best OR mild-moderate coughing, wheezing, shortness of breath or other symptoms that interfere with the ability to perform his/her usual activities. Symptoms are not severe, but the participant may have to stop his/her activities to rest.	The participant received instructions on name/dose/frequency of rescue medication and prompted to re-check peak flow and/or symptoms 20 minutes after rescue medication dose. If the participant recorded ≥ 2 consecutive readings in the Yellow Zone in ≤ 48 hours, the participant was instructed to contact his/her healthcare provider.**
Red Zone	Peak flow reading $\leq 50\%$ of participant's personal best OR asthma symptoms are severe, and the participant is unable to perform his/her usual activities. Symptoms of abdominal breathing, inability to complete sentences, and extreme fatigue may be present.	The participant received instructions on name/dose/frequency of rescue medication. The participant was instructed to seek emergency medical attention immediately if symptoms worsen or fail to improve with treatment. The participant was prompted to re-check peak flow and/or symptoms 20 minutes after rescue medication dose. If the participant initially improved but subsequently entered another (consecutive) Red Zone reading, the participant was instructed to contact his/her healthcare provider. If the participant entered severe symptoms such as "lips turning blue," "trouble talking" or "throat tight," the application screen immediately and automatically navigated to a shortcut link prompting the participant to "Call 911/EMS" for emergency assistance.**
** At enrollment, all participants were instructed that the AAP was not a substitute for emergency or routine medical care and they were instructed to keep regularly scheduled medical appointments and to seek urgent medical attention in case of emergency. Research staff and the parent/caregiver received email notification if the participant entered data that triggered an alert to notify/call the doctor, seek emergency medical care or "call 911." These notification measures were for added patient safety to ensure that appropriate medical care was sought.		

Figure 1. Personalized asthma action plan instructions for each zone. The application automatically navigated the participant's personalized treatment zone based on the data (peak flow or symptoms) entered by the adolescent on his/her smartphone device.

Paper-based AAP participants were instructed to use their AAP for daily care and worsening symptoms. At enrollment, they were provided a monthly paper diary to record daily peak flow and/or symptoms. To reduce the risk of lost diaries, blank paper diaries were mailed to participants each month, and they were asked to return completed diaries to the study team monthly via a self-addressed envelope.

Every participant completed the Asthma Control Test (ACT)¹¹ and the child self-efficacy questionnaire¹² at baseline and at the end of the 6-month intervention. The ACT is a 5-item validated, self-report questionnaire designed to assess asthma control in the past 4 weeks. Responses yield a total score (range, 5–25), with scores of 19 or less indicating uncontrolled asthma. The child asthma self-efficacy questionnaire is a 14-item validated questionnaire (total score range, 14–70 points) designed to measure

child self-efficacy with regard to attack prevention and attack management.¹² The Cronbach α reliability was 0.75.¹²

We estimated a sample size of 17 in each group to have at least 80% power to detect a median difference of 4 in change from baseline ACT between the 2 groups assuming an SD of 3.75. Sample size calculation was performed using the software PASS 11 (NCSS, LLC, Kaysville, Utah) assuming a 2-sided significance level of 5%. We summarized baseline characteristics and outcomes using descriptive statistics, such as frequency and percentages for categorical variables and medians and quartiles for continuous outcomes. Baseline characteristics were compared between the smartphone- and paper-based groups using the Fisher exact test and Wilcoxon rank sum test as appropriate. Changes from baseline to 6 months in asthma self-efficacy and ACT scores were compared using Wilcoxon rank sum test. We also compared self-efficacy and ACT scores

Table 1
Demographic Characteristics of the Study Participants^a

Characteristic	All (N = 34)	Smartphone AAP group (n = 17)	Paper AAP group (n = 17)	P value
Age, y	15.4 (14.3–16.3)	15.3 (14.4–16.8)	15.4 (13.4–16.1)	.36
Male sex	13 (38)	5 (29)	8 (47)	.48
Race				.72
African- American	21 (62)	11 (65)	10 (59)	
White	12 (35)	5 (29)	7 (41)	
American Indian/Alaska Native	1 (3)	1 (6)	0	
Insurance				.68
Private	9 (26.5)	4 (23.5)	5 (29.4)	
Medicaid	12 (35.3)	5 (29.4)	7 (41.2)	
ARKids	13 (38.2)	8 (47.1)	5 (29.4)	
Annual household income, \$ ^b				.36
≤14,999	5 (17.8)	3 (21.4)	2 (14.2)	
15,000–29,999	14 (50.0)	8 (57.1)	6 (42.9)	
30,000–60,000	8 (28.6)	2 (14.3)	6 (42.9)	
>60,000	1 (3.6)	1 (7.2)	0	
Baseline Asthma Control Test score	21 (17–24)	21 (18–24)	20 (17–24)	.86

Abbreviation: ARKids, Arkansas' State Child Health Insurance Plan.

^aFor continuous variables, data are presented as median (interquartile range) and Wilcoxon rank sum test *P* values are reported; for categorical variables, data are presented as number (percentage) of patients and Fisher exact test *P* values are reported.^bData were missing for some participants.

between the 2 groups after stratifying patients based on the level of asthma control at baseline (≤ 19 or > 19). Six of the 34 participants (18%) did not complete the survey at the end of the 6-month intervention period and did not log use in diaries or in the app. These participants were considered lost to follow-up. A per-protocol analysis was conducted, and the comparison of AAP use, ACT scores, and self-efficacy scores was analyzed among those who completed the study to avoid imputation of missing outcomes. Two-sided $P \leq .05$ was considered statistically significant. All analyses were conducted using the statistical software package R.¹³

Results

Of the 34 enrolled participants, median age was 15.4 years and 62% were African American (Table 1). Most participants (70%) had state-issued health insurance (either Medicaid [41%] or Arkansas' State Child Health Insurance Plan [29%]). Participants represented a mix of urban (68%) and rural (32%) adolescents. Of the 17 intervention participants, 15 (88%) had a monthly data package, and 2 (12%) had pay as you go minutes. The median baseline ACT score for the overall study population was 21; however, 15 adolescents (7 in the smartphone group in 8 in the paper group) had baseline ACT scores of 19 or less, indicating uncontrolled asthma. Participants were experienced with smartphone use and mobile applications, with 97% of adolescents stating that they had downloaded and used an app on a smartphone before enrollment. Similarly, 97% adolescents stated that they had used a smartphone to access the internet before enrollment.

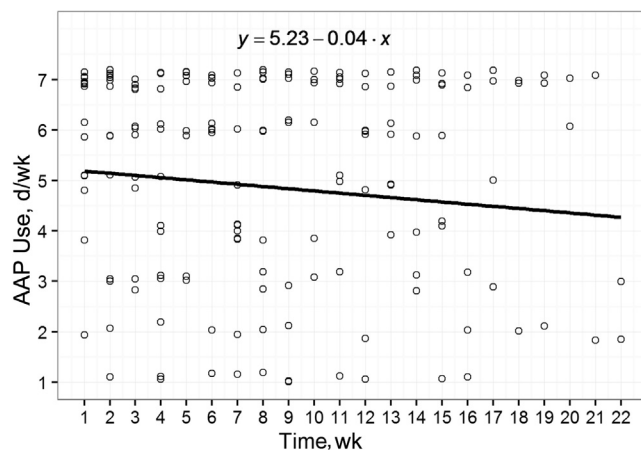
AAP Use

During the 6-month study period, adolescents in the smartphone group accessed the smartphone AAP a median of 4.36 days per week. Furthermore, adolescents accessed the smartphone AAP a median of 12.17 times per week, indicating that some participants accessed the application multiple times per day on some days. We examined use of the smartphone AAP over time. There was a downward trend of AAP use, with a decrease of 0.04 days per week during the 6-month study; however, this trend was not statistically significant ($P = .14$) (Fig 2). Although participants accessed the smartphone application frequently, use of the electronic diary to record medications, peak flow, and symptoms was low. Three participants failed to log any medications, peak flow, or symptoms data during the 6-month period, and only 1 participant logged at least once per week for the entire study period. Even though they

accessed the AAP frequently throughout the week, smartphone AAP participants completed the electronic diary a median of only 10 days per month. Diary use rates were better for the paper AAP group, with 6 participants (35.3%) returning all 6 diaries and 3 participants returning 0 diaries during the 6-month study period. Overall, paper AAP participants completed the paper diary a median of 23 days per month, which was a significantly higher diary completion rate compared with the smartphone AAP group ($P = .03$).

Patient Outcomes

For the overall population, there were no statistically significant changes in ACT scores between groups after the 6-month intervention. The median ACT score for the smartphone group was 21 before and 22 after the intervention; for the paper group, the median ACT score was 20 before and 21 after the intervention. During analysis, participants were stratified based on the level of asthma control at baseline. In the uncontrolled smartphone group, the median ACT score improved from 11 before to 20 after the intervention ($P = .04$). There was no change in median ACT score among participants in the paper group with uncontrolled asthma, with median scores of 17 before and 17 after the intervention ($P = .64$) (Fig 3). Asthma self-efficacy scores did not significantly change for either group, with the smartphone group having a median self-

**Figure 2.** Asthma action plan (AAP) use over time. AAP use decreased by 0.04 days per week during the 6-month intervention ($P = .14$).

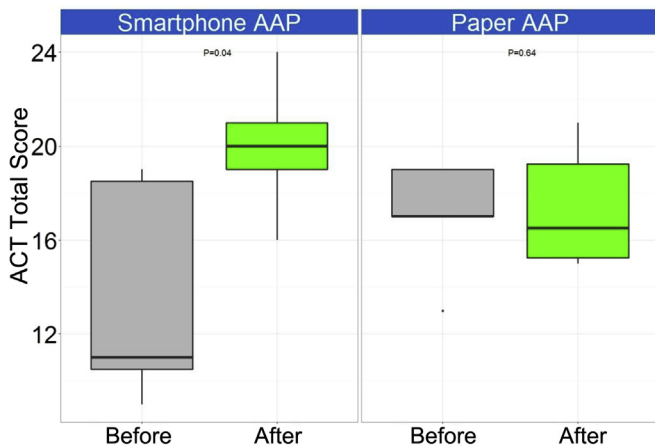


Figure 3. Distribution of Asthma Control Test (ACT) scores before and after the intervention for the paper AAP and the smartphone AAP groups among patients with uncontrolled asthma at baseline. There was a significant change in ACT score for the smartphone group ($P = .04$) but not the paper group ($P = .64$). Solid horizontal lines inside the boxes represents the median.

efficacy score of 61 before and 62 after the intervention and the paper group having a median self-efficacy score of 62 before and 60 after the intervention. There was no significant change in self-efficacy for either group when stratified by baseline asthma control.

Patient Satisfaction

We assessed participant satisfaction among the smartphone group only at the end of the 6-month intervention (Table 2). Twelve of the 17 smartphone AAP participants completed the post-intervention satisfaction survey; 92% stated they would like to continue using the application, and 100% stated they would recommend the application to a friend with asthma. When questioned about specific features of the application, most thought the application helped them better control asthma (75%), thought reminders helped them remember to take their medications (83%), and liked receiving the asthma tips and education via push notification (83%). Thirty-three percent thought the application had too many reminders.

Discussion

Mobile health (mHealth) technology integrates into today's societal trends of frequent and daily smartphone use by adolescents. In national studies, most US adolescents report frequent smartphone use, with 73% having smartphone access and 91% stating they access the internet using a mobile device.⁷ Similar to these national trends, our study population, representing both rural and urban adolescents, reported high smartphone use rates. Eighty-eight percent had data packages vs pay as you go minutes, and 97% reported they used smartphones to download mobile applications and to access the internet before enrollment. The fact that smartphone technology is so ubiquitous in the lives of adolescents makes it a potentially feasible and acceptable technology-based solution that can be integrated into adolescents' daily routines. Furthermore, because adolescents are traditionally difficult to engage and at high risk for poor asthma outcomes,^{4–6} clinicians and researchers should continue to seek innovative techniques to engage them in an effort to improve self-management skills and health outcomes.

Similar to prior results,⁹ adolescents with uncontrolled asthma had improved ACT scores after using the smartphone AAP during the 6-month study period. Although these results were not statistically significant, they may indicate a specific target population for

Table 2

Postparticipation Satisfaction Survey (Smartphone Group Only)

Survey response	No. of patients who agree or strongly agree/total no. of patients (%)
1. Would like to keep using the mobile app	11/12 (92)
2. Would recommend app to a friend with asthma	12/12 (100)
3. Mobile app helped me keep my asthma under better control	9/12 (75)
4. Like using technology to help manage my health	11/12 (92)
5. Reminders helped me remember to take my medications	10/12 (83)
6. Mobile app had too many reminders	4/12 (33)
7. Liked receiving asthma tips and messages	10/12 (83)

future larger studies. Schatz et al¹⁴ describe a minimally important difference of 3 points on the ACT as clinically relevant. A larger study would be better powered to observe these differences in patients with uncontrolled asthma. The negative results of this pilot study further support the current literature^{8,9,15,16} that a one-size-fits-all approach is unlikely to be effective given the large heterogeneity in patient and disease characteristics among asthma populations. Researchers and clinicians should consider tailored and personalized mobile-based solutions designed to address certain patient characteristics, such as the patient's underlying level of asthma control. More investigation needs to be conducted regarding the effect of social determinants, such as geographic location (rural vs urban), access to subspecialty care, and socioeconomic status, to ensure that these factors are considered in the design of technology-based solutions.

Overall, use of the daily diaries did not appear to be effective in either group. Smartphone AAP users logged in the electronic diary 10 days per month compared with the paper group, who logged 23 days per month in the paper diary. Unlike the electronic diaries that are time stamped and impossible to backfill, paper diaries can be backfilled by patients, so there is no way to distinguish whether the diaries were completed in real time. Regardless of whether adolescents in the paper group logged in their diaries in real-time or backfilled diaries, more frequent logging did not result in better outcomes for the paper AAP group. This finding, coupled with the fact that the smartphone AAP group only logged 10 days per month, suggests that neither paper nor electronic diaries are likely to be effective stand-alone self-management tool for adolescents.

Although we initially hypothesized that the smartphone group would have improved asthma control because of improved self-efficacy, our hypothesis was not supported by the findings. Self-efficacy is the belief in one's ability to perform a behavior. Improvement in asthma control without improvement in self-efficacy may have occurred because adolescents were simply reacting to the prompts or cues to action (ie, medication reminders). They may not have been confident in their ability to act without the aid of the application. More studies are needed to delineate which specific features of the application are most effective in improving both clinical and behavioral outcomes for adolescents.

Our study adds to the increasing asthma mHealth literature because it is one of the few randomized studies conducted during a 6-month period. Most currently published asthma mHealth trials describe short-term studies and nonrandomized trials.^{8,16–19} The application's design was tailored based on input and feedback of adolescents with asthma and their caregivers. The importance of the contribution of adolescents in the overall design of smartphone applications has been recognized by others²⁰ and likely contributed to the frequent and sustained use of the application (median, 4.36 days per week). Another strength of our study includes the baseline

training and education received before randomization. This education served to ensure that each participant knew the purpose of his/her AAP, how to use it, and how to report symptoms and use common asthma devices, peak flow meters, and metered-dose inhalers before randomization.

One limitation includes the small number of participants. This investigation was designed to be a pilot study to examine AAP use rates and outcomes during a 6-month period. Participants were randomized into treatment groups without consideration of baseline characteristics, such as ACT scores; thus, subgroup analysis should be interpreted with caution. A larger sample size would have allowed for stratification of participants based on ACT scores before randomization and could have potentially helped in determining the effect of the intervention on asthma outcomes among adolescents with varying degrees of baseline asthma control. On the basis of these pilot findings, we will plan future studies to include larger study populations to allow for stratification of participants by baseline and other disease-specific characteristics. Despite this limitation, we were able to examine the minimally important difference in ACT scores based on the study by Schatz et al.¹⁴ to assess for clinically relevant changes in ACT scores among the 2 treatment groups. Our findings, although not statistically significant, suggest an association between use of the smartphone AAP and potentially clinically relevant improvements in ACT score (change ≥ 3 points) over time compared with use of a paper AAP. Another potential limitation of our study is that the analysis was performed on a per-protocol population in which we only analyzed patients who completed the study, which has a potential for biased results of unknown magnitude and direction.

Another limitation included lack of medication adherence monitoring. Several application features were designed to improve medication adherence, including access 24 hours per day 7 days per week to prescribed medications, with real-time medication dosing feedback, daily medication reminders, and asthma education delivered directly to the adolescent's smartphone. Although there was no trend to suggest significant "app fatigue" over time (Fig 2), we did not examine the effect of the use of specific application features on medication adherence because it was beyond the scope of this small pilot study. Bluetooth-enabled medication devices allow for electronic capture of medication dosing and do not require the patient to take extra steps to record medication doses. This technology would preclude the need for electronic or paper diaries to record medication doses; however, several devices exist,^{21–23} and none are compatible with every available preventive or rescue medication. Because we did not provide medications for study participants, participants taking controller medications incompatible with a specific monitoring device would have been excluded, and thus the small population would have been skewed to include only one particular type or brand of preventive medication (ie, meter-dose inhaler vs dry powder inhaler vs pill). A larger-scale study will allow for more flexibility to include Bluetooth-enabled monitoring devices to measure medication adherence.

While continuing to examine mHealth technology use among adolescents, future investigations should explore the effect of disease-specific characteristics, such as underlying asthma control and asthma severity, patient characteristics, and social determinants of health. Incorporation of health behavior theory to better understand adherence and corresponding mHealth technology use will inform future studies. Using a theoretical framework, such as the Health Belief Model, a commonly used explanatory theory of health behavior that has been applied to adolescents²⁴ and specifically to beliefs about medication adherence and asthma management among those with asthma,²⁵ can guide this exploration. Understanding these behaviors can help

clinicians develop effective and tailored mHealth treatment interventions that integrate with adolescents' preferences and technology use.⁷

References

- [1] Akinbami LJ, Moorman JE, Bailey C, et al. Trends in asthma prevalence, health care use, and mortality in the United States, 2001–2010. *NCHS Data Brief*. 2012;94:1–8.
- [2] National Heart, Lung, and Blood Institute. *National Asthma Education and Prevention Program Expert Panel Report 3: Guidelines for the Diagnosis and Management of Asthma*. Bethesda, MD: National Heart, Lung, and Blood Institute; 2007. NIH publication 07-4051.
- [3] Simon AE, Akinbami LJ. Asthma action plan receipt among children with asthma 2–17 years of age, United States, 2002–2013. *J Pediatr*. 2016;171:283–289.e1.
- [4] MacDonald P. Understanding and treating asthma in adolescents. *Paediatr Nurs*. 2003;15:34–36.
- [5] Naimi DR, Freedman TG, Ginsburg KR, Bogen D, Rand CS, Apter AJ. Adolescents and asthma: why bother with our meds? *J Allergy Clin Immunol*. 2009;123:1335–1341.
- [6] Blaakman SW, Cohen A, Fagnano M, Halterman JS. Asthma medication adherence among urban teens: a qualitative analysis of barriers, facilitators and experiences with school-based care. *J Asthma*. 2014;51:522–529.
- [7] Lenhart A. *Teens, Social Media and Technology Overview 2015*. Pew Research Center, 2015 <http://www.pewinternet.org/2015/04/09/teens-social-media-technology-2015/> Accessed January 7, 2016.
- [8] Wu AC, Carpenter JF, Himes BE. Mobile health applications for asthma. *J Allergy Clin Immunol Pract*. 2015;3:446–448.e1–16.
- [9] Burbank AJ, Lewis SD, Hewes M, et al. Mobile-based asthma action plans for adolescents. *J Asthma*. 2015;52:583–586.
- [10] Piwik. <http://piwik.org/>. Accessed February 12, 2016.
- [11] Nathan RA, Sorkness CA, Kosinski M, et al. Development of the asthma control test: a survey for assessing asthma control. *J Allergy Clin Immunol*. 2004;113:59–65.
- [12] Bursch B, Schwankovsky L, Gilbert J, Zeiger R. Construction and validation of four childhood asthma self-management scales: parent barriers, child and parent self-efficacy, and parent belief in treatment efficacy. *J Asthma*. 1999;36:115–128.
- [13] R Core Team. *R: A Language and Environment for Statistical Computing* [computer program]. Vienna, Austria: The R Foundation; 2005. <http://www.R-project.org/>.
- [14] Schatz M, Kosinski M, Yarlas AS, Hanlon J, Watson ME, Jhingran P. The minimally important difference of the Asthma Control Test. *J Allergy Clin Immunol*. 2009;124:719–723.
- [15] Hui CY, Walton R, McKinstry B, Jackson T, Parker R, Pinnock H. The use of mobile applications to support self-management for people with asthma: a systematic review of controlled studies to identify features associated with clinical effectiveness and adherence [published online October 2, 2016]. *J Am Med Inform Assoc*. <http://dx.doi.org/10.1093/jamia/ocw143>.
- [16] Marciano Belisario JS, Huckvale K, Greenfield G, Car J, Gunn LH. Smartphone and tablet self management apps for asthma. *Cochrane Database Syst Rev*. 2013;11:CD010013.
- [17] Farooqui N, Phillips G, Barrett C, Stukus D. Acceptability of an interactive asthma management mobile health application for children and adolescents. *Ann Allergy Asthma Immunol*. 2015;114:527–529.
- [18] Mulvaney SA, Ho YX, Cala CM, et al. Assessing adolescent asthma symptoms and adherence using mobile phones. *J Med Internet Res*. 2013;15:e141.
- [19] Johnson KB, Patterson BL, Ho YX, et al. The feasibility of text reminders to improve medication adherence in adolescents with asthma. *J Am Med Inform Assoc*. 2016;23:449–455.
- [20] Schneider T, Panzera AD, Couluris M, Lindenberger J, McDermott R, Bryant CA. Engaging teens with asthma in designing a patient-centered mobile app to aid disease self-management. *Telemed J E Health*. 2016;22:170–175.
- [21] Patel M, Pilcher J, Travers J, et al. Use of metered-dose inhaler electronic monitoring in a real-world asthma randomized controlled trial. *J Allergy Clin Immunol Pract*. 2013;1:83–91.
- [22] Chan AH, Stewart AW, Harrison J, Camargo CA Jr, Black PN, Mitchell EA. The effect of an electronic monitoring device with audiovisual reminder function on adherence to inhaled corticosteroids and school attendance in children with asthma: a randomised controlled trial. *Lancet Respir Med*. 2015;3:210–219.
- [23] Foster JM, Smith L, Usherwood T, Sawyer SM, Rand CS, Reddel HK. The reliability and patient acceptability of the SmartTrack device: a new electronic monitor and reminder device for metered dose inhalers. *J Asthma*. 2012;49:657–662.
- [24] Eisen M, Zellman GL, McAlister AL. A Health Belief Model-Social Learning Theory approach to adolescents' fertility control: findings from a controlled field trial. *Health Educ Q*. 1992;19:249–262.
- [25] Braun-Fahrlander C, Gassner M, Grize L, et al. Comparison of responses to an asthma symptom questionnaire (ISAAC core questions) completed by adolescents and their parents. SCARPOL-Team. Swiss Study on Childhood Allergy and Respiratory Symptoms with respect to Air Pollution. *Pediatr Pulmonol*. 1998;25:159–166.