Ann Allergy Asthma Immunol 125 (2020) 581–588

Contents lists available at ScienceDirect

Developing and evaluating ASTHMAXcel adventures

A novel gamified mobile application for pediatric patients with asthma

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ARTICLE INFO

Article history:
Received for publication April 16, 2020.
Received in revised form July 12, 2020.
Accepted for publication July 13, 2020.

ABSTRACT

Background: The ASTHMAXcel mobile application has been linked to favorable outcomes among adult patients with asthma.
Objective: To assess the impact of ASTHMAXcel Adventures, a gamified, guideline-based, pediatric version on asthma control, knowledge, health care utilization, and patient satisfaction.
Methods: Pediatric patients with asthma received the ASTHMAXcel Adventures mobile intervention on-site only at baseline (visit 1), 4 months (visit 2), and 6 months (visit 3). The asthma control test, asthma illness representation scale—self-administered, pediatric asthma impact survey, and Client Satisfaction Questionnaire-8 were used to assess asthma control, knowledge, and patient satisfaction. Patients reported the number of asthma-related emergency department (ED) visits, hospitalizations, and oral prednisone use.
Results: A total of 39 patients completed the study. The proportion of controlled asthma increased from visit 1 to visits 2 and 3 (30.8% vs 53.9%, $P = .04$; 30.8% vs 59.0%, $P = .02$), and largely seen in boys. The mean asthma illness representation scale—self-administered scores increased from baseline pre- to postintervention, with sustained improvements at visits 2 and 3 (3.55 vs 3.76, $P < .001$; 3.55 vs 3.80, $P = .001$; 3.55 vs 3.99, $P < .001$). The pediatric asthma impact survey scores improved from baseline to visits 2 and 3 (43.33 vs 34.08, $P < .001$; 43.33 vs 31.74, $P < .001$). ED visits and prednisone use significantly decreased from baseline to visits 2 and 3 (ED: 0.46 vs 0.13, $P = .03$; 0.46 vs 0.02, $P = .02$; prednisone use, 0.49 vs 0.13, $P = .02$; 0.49 vs 0.03, $P = .003$. Satisfaction was high with mean client satisfaction questionnaire score of approximately 30 (out of 32) at all visits.
Conclusion: ASTHMAXcel Adventures improved asthma control, knowledge, and quality of life, and reduced ED visits and prednisone use with high satisfaction scores.

Introduction

Asthma is one of the most common chronic conditions affecting children in the United States, with an estimated prevalence of approximately 8.9%.[1,2] Uncontrolled pediatric asthma severely affects patients and their families, and simultaneously placing a tremendous burden on the US economy through increased rates of absenteeism and increased health care utilization.[3] One study estimated that uncontrolled pediatric asthma could accrue up to $3.4 billion in direct health care costs and $345 million from lost productivity between 2015 to 2020.[4] Asthma management guidelines are linked to reductions in asthma morbidity, focusing on patient education, monitoring asthma symptoms, and optimizing medications and adherence.[5-9] However, outpatient settings face critical time constraints and other barriers to the delivery of guideline-based asthma care. One survey of practitioners found that only approximately 5% utilize asthma action plans for their

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Brian C. Hsia, Anjani K. Singh, Obumneme Njeze and Emine Cosar are co-first authors and have contributed equally to this work.
Disclosures: The authors have no conflicts of interest to report.
Funding: This work was funded by the American Lung Association/American Academy of Allergy, Asthma & Immunology Foundation Allergic Respiratory Diseases Research Award.

https://doi.org/10.1016/j.anai.2020.07.018
1081-1206/

patients, whereas another found few patients used asthma action plans at the initiation of their study.[10,11] Digital technologies have great potential to bridge these gaps at minimal cost while enhancing the partnership between patients and providers.

The nearly ubiquitous access to mobile devices by patients and caregivers has contributed to the increasing use and availability of mobile health (mHealth) applications for asthma. Approximately 95% of teens own a smartphone with almost no difference in smartphone access among Hispanic, non-Hispanic white, and non-Hispanic black adolescents.[12] Prevalent smartphone access among teens equalizes access to the internet and its associated benefits for underrepresented minority groups because minority teens are less likely to own a home computer or have home broadband access.[13] Notably, video game behaviors are also increasing among teens, with 90% playing some form of video games irrespective of device type.[12] Such engaging interfaces help retain users to digital interventions, as shown in other mHealth studies, with 1 reporting an 86% retention rate at 20 weeks.[14] The need for creating an appealing, evidence-based mHealth application is increasingly apparent, given the surplus of available mobile applications. There are more than 325,000 mHealth applications available on Android and Apple app stores, and 78,000 mHealth applications are estimated to be added per year.[15,16] In 2017 alone, there were an estimated 3.6 billion total downloads of mHealth applications.[15,16] Despite the growing field of mHealth applications, many have a poor quality design, especially those designed for asthma management.[17] Creation of improved designs and engaging interfaces is crucial because many digital interventions suffer from exponential attrition.[18]

This study was conducted at the Montefiore Asthma Center (MAC) in the Bronx, New York. The Bronx bears the heaviest asthma burden of all New York City boroughs and New York State counties.[19,20] The overall asthma-related mortality rate of the Bronx alone is substantially higher than the national average, with most recent estimates of 43.5 vs 9.9 per 1 million per year.[2,20] Asthma-related health care utilization in the Bronx is also alarmingly high, with annual emergency department (ED) and hospitalization rates at 384 and 51 per 10,000 in the Bronx vs 56 and 6 nationally.[2,19] The MAC provides an advantageous location for the study, providing access to a population with a high asthma burden. To offer an evidence-based, user-friendly, and personalized approach, we developed ASTHMAXcel Adventures, a gamified mobile application (iOS and Android-based) for young patients with asthma. The aims of this study were as follows: (1) to evaluate the impact of ASTHMAXcel Adventures on asthma control (primary outcome), knowledge, and quality of life; (2) to evaluate its impact on asthma-related ED visits, hospitalizations, and oral prednisone use; and (3) to evaluate process outcomes including user satisfaction and utilization time. We hypothesized that ASTHMAXcel Adventures would improve asthma control and knowledge, reduce utilization, and achieve high user satisfaction.

Methods

Study Design

We conducted a single-arm, prospective study of patients with asthma who received asthma education from the ASTHMAXcel Adventures mobile application by means of an iPad tablet on-site at the MAC between May 1, 2018 and July 10, 2019. Study participants were pediatric patients ranging from 7 to 17 years old. Inclusion criteria included the following: (1) children with a history of physician-diagnosed persistent asthma defined by the National Heart, Lung, and Blood Institute[21]; (2) use of daily controller inhaler medications; (3) English-speaking; and (4) smartphone (iOS or Android) access at home. Exclusion criteria included the following: (1) use of oral corticosteroids in the 2 weeks before visit 1; (2) pregnancy; and (3) severe cognitive or psychiatric conditions that precluded a study participant from understanding and completing the study protocol. This study was approved by the institutional review board at the Albert Einstein College of Medicine, Bronx, New York. Informed assent and consent were obtained by means of a written form from the study participant or their parent or guardian.

ASTHMAXcel Adventures Mobile Application

We developed ASTHMAXcel Adventures for iOS and Android smartphone and tablet devices as an interactive mobile application with touch screen functionality. The application includes brief (1-2 minutes) educational videos and interactive games developed by our team, combining animations with informative narration. The software program has an introductory, maplike screen with 5 levels to choose from (Fig 1). Each level consists of 1 to 3 educational videos and chapters followed by a corresponding game, requiring users to answer questions regarding the videos seen in the selected chapter.

There are 11 chapters available to the patient. Each chapter is designed to reflect the National Asthma Education and Prevention Program guidelines.[21] They are also consistent with the 2019 British Thoracic Society and Scottish Intercollegiate Guidelines Network guidelines, which includes a section supporting the use of digital interventions for asthma self-management, and the 2018 Global Initiative for Asthma guidelines.[22,23] All educational content was developed and reviewed by our team of asthma physicians, educators, and a behavioral scientist to ensure consistency with these guidelines. During each of the 3 sessions, participants completed chapters as outlined in Table 1 (without any involvement or help from their parents).

Pilot Testing ASTHMAXcel Adventures

Development of ASTHMAXcel Adventures was largely based on the protocol and findings from pilot testing the adult version of ASTHMAXcel, and a literature review of mHealth studies.[24,25] After the creation of our first fully functional version, we continued to refine ASTHMAXcel Adventures through feedback from participants immediately after completing each visit. This process served primarily to debug our app (ie, repair previously unrecognized or unexpected coding error) and did not alter the content or interface. This feedback was facilitated by our study coordinator, asking for the overall user experience in an unscripted format. Feedback elicited by our study coordinator was promptly evaluated and included, if deemed appropriate, as an update to our application to allow for a more user-centered experience at the following visits.

Assessments

For the primary outcome, asthma control, we assessed asthma symptom burden through the Asthma Control Test (ACT) designed for those aged 12 to 17 years and the Childhood Asthma Control Test (cACT) for those aged 4 to 11 years.[26-28] The ACT is a 5-item questionnaire used to evaluate asthma control in patients over the past 4 weeks.[26] The cACT is a 7-item questionnaire evaluating similar metrics as the ACT, but with the first 4 questions assessing the present time and the last 3 questions (answered by the patient's parent or guardian) assessing the past 4 weeks.[27,28] A higher score on the ACT and cACT indicates overall better asthma control.[28,29] For both the ACT and cACT, well-controlled asthma was defined as a total score greater or equal to 20.[30] Asthma control was analyzed as binary for the whole sample analysis.

Asthma knowledge was assessed through the Facts About Asthma subscale of the Asthma Illness Representation Scale—Self Administered (AIRS-SR).[31] At visit 1, a preintervention AIRS-SR was administered before the participant was exposed to the ASTHMAXcel

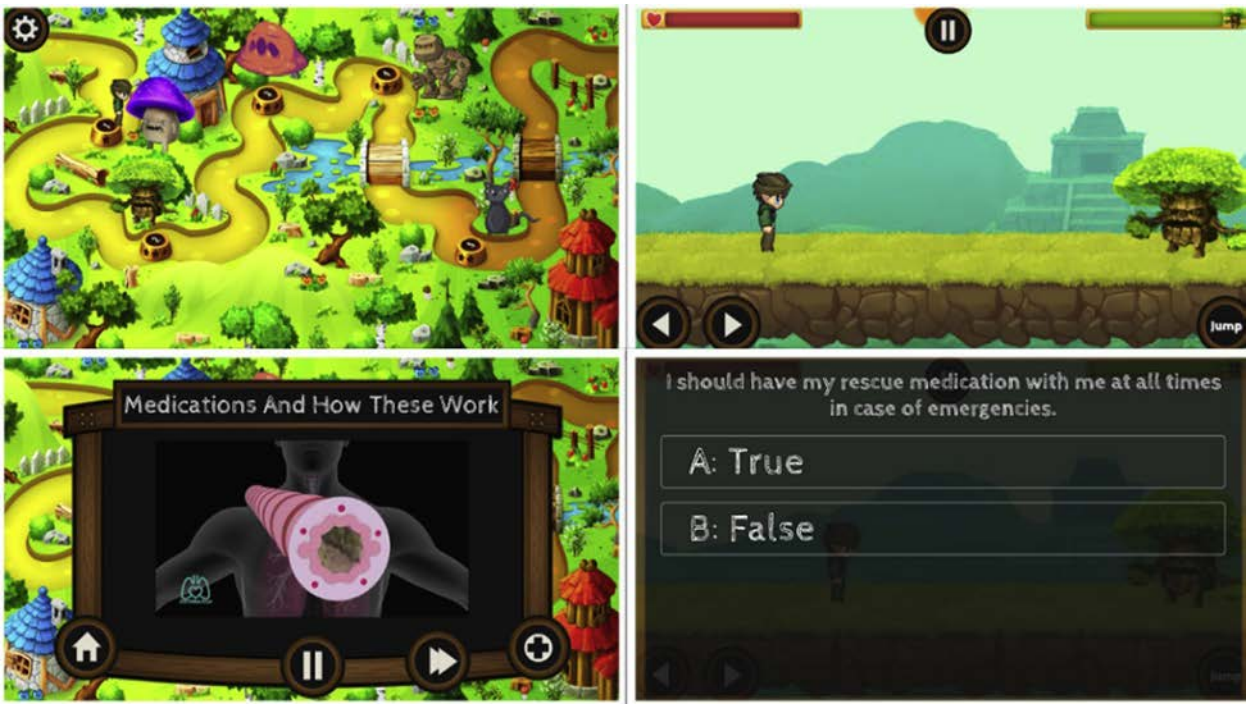

Figure 1. ASTHMAXcel Adventures mobile application sample images.

Adventures mobile application, and a postintervention AIRS-SR was administered afterward. AIRS-SR was also administered after the intervention at visits 2 and 3. This questionnaire consists of 13 asthma guideline-based questions drawn from asthma management guidelines.[31] AIRS-SR scores range from 1 to 5, with a higher score indicating better asthma knowledge.

Asthma-related quality of life was assessed using the National Institutes of Health Patient-Reported Outcomes Measurement Information System (NIH PROMIS) Pediatric Asthma Impact Scale (PAIS), which was completed by the caregiver.[32,33] The PAIS is a 17-item questionnaire consisting of multiple domains that describe the impact of asthma on one's life.[32,33] The PAIS uses a 1-week time frame for all questions.[32,33] The total score ranged from 17 to 85 with a lower score on the PAIS indicating a better quality of life.[32,33]

Health care utilization (ED visits, hospitalizations, and prednisone use) was evaluated over the previous 2-month period from each respective visit. We assessed patient satisfaction with the intervention by using the Client Satisfaction Questionnaire–8 (CSQ-8).[34,35] This satisfaction questionnaire consists of 8 questions regarding the understanding of information, comprehensiveness, comfort level, general satisfaction, and ease of use.[34,35] The total score ranged from 8 to 32, with a higher score reflecting greater satisfaction with the intervention.[34,35] Intervention completion time was also measured at each visit. We securely collected and stored data through our Research Electronic Data Capture project database.

Statistical Analysis

Patient baseline characteristics were summarized as mean and SD for continuous variables and as frequencies and percentages for categorical variables and compared between boys and girls using the 2-sample t tests or Wilcoxon rank-sum test for continuous variables and Pearson's χ^2 test or Fisher's exact test for categorical variables. Paired t tests were used to compare ACT scores between visits among 12 to 17 years old and cACT scores among 4 to 11 years old, respectively. The primary outcome of this study was asthma control measured by ACT and cACT defined as a total score of greater than or equal to 20. The rates of well-controlled asthma were compared between visits using McNemar's tests. Pearson's correlations were computed to assess whether the changes between visits were associated with potential confounders, such as baseline age, sex, parental education, and time between visits; generalized linear mixed model (GLLM) was used to assess these associations, adjusting for potential confounders. Because a significant correlation was found between sex and changes in asthma control between visits, all analyses were stratified by sex whenever appropriate, and GLLM was used to test an interaction effect between sex and visits to assess whether the changes in asthma control differed between boys and girls when adjusting for potential confounders. Secondary outcome measures, including asthma knowledge (AIRS-SR), quality of life (PAIS), utilization scores (ED, hospitalizations, oral prednisone use), and process outcomes (satisfaction [CSQ-8], time spent), were analyzed as continuous variables. Values at each visit and differences between visits were summarized. Paired t tests were used to compare these outcomes between the visits. Pearson's correlations were also assessed between the changes between visits and each of the potential confounders; linear mixed models were used to assess these associations while adjusting for potential confounders. All analyses were conducted with the statistical software, Statistical Analysis System 9.4 (SAS Institute, Cary, North Carolina). The statistical significance level was set as $P < .05$.

Results

Patient Characteristics

A total of 49 patients were initially recruited in our study. Notably, 10 patients did not complete visit 3, the primary time point for our study, and thus excluded from the analysis. Thus, 39 patients were included in the final analysis (Table 2). Among the study participants, the baseline age ranged from 7.1 to 16.0 years, with a mean of 10.5. Most participants were Hispanic (53.9%) or non-

Table 1
ASTHMAXcel Adventures Chapters, Game Levels, and Study Visits

Chapter	Topic	Game level	Visit number
1	How asthma affects your airways	1	1
2	Medications and how these work	2	1
3	Priming	2	1
4	How to use an inhaler and spacer	3	2
5	How to use a peak expiratory flow rate meter	3	2
6	Asthma action plan	3	2
7	Environmental control: pets, roaches, and mice	4	2
8	Environmental control: molds and dust mites	4	2
9	Secondhand smoke	5	3
10	Exercise-induced asthma	5	3
11	Cleaning parts	5	3

Hispanic black (41.0%). Most patients were covered by Medicaid (66.7%), and all patients had access to a smartphone and internet. Baseline characteristics did not differ significantly between boys and girls.

Primary Outcome: Asthma Control

For the entire sample, mean cACT scores among 7 to 11 years old increased significantly from visit 1 to visits 2 and 3 (17.42 vs 19.63, $P = .02$; 17.42 vs 20.46, $P < .001$). Mean ACT scores among 12 to 17 years old increased significantly from visit 1 to visit 2 (16.45 vs 21.55, $P = .008$). When stratified by sex, cACT and ACT increased significantly ($P \leq .02$) among boys at visits 2 and 3 relative to visit 1 for the entire sample and for each age category, but not among girls ($P \geq .13$) (Table 3).

Well-controlled asthma was defined as a cACT or ACT less than or equal to 20.[30] When analyzing the entire sample, the proportion of well-controlled patients increased significantly from visit 1 to visits 2 and 3 (30.8% vs 53.9%, $P = .04$; 30.8% vs 59.0%, $P = .02$).

Table 2
Participants Baseline Characteristics

Parameter	All (n = 39)	Boys (n = 20)	Girls (n = 19)	*P* value[a]
Age, mean (SD), y	10.5 (2.6)	10.5 (2.6)	10.6 (2.6)	.93
Race & ethnicity, n (%)				.40
Hispanic	21 (53.9)	12 (60.0)	9 (47.4)	
Non-Hispanic white	2 (5.1)	0 (0)	2 (10.5)	
Non-Hispanic black	16 (41.0)	8 (40.0)	8 (42.1)	
Parental education, n (%)				.27
Did not complete high school	10 (25.6)	4 (20.0)	6 (31.6)	
Completed high school	13 (33.3)	9 (45.0)	4 (21.1)	
Completed college	11 (28.2)	4 (20.0)	7 (36.8)	
Higher degree	1 (2.6)	0 (0)	1 (5.3)	
Other	4 (10.3)	3 (15.0)	1 (5.3)	
Language spoken, n (%)				.24
English	19 (48.7)	11 (55.0)	8 (42.1)	
Spanish	1 (2.6)	1 (5.0)	0	
English and Spanish	15 (38.5)	5 (25.0)	10 (52.6)	
Other	4 (10.3)	3 (15.0)	1 (5.3)	
Insurance, n (%)				.37
Medicaid	26 (66.7)	15 (75.0)	11 (57.9)	
Private	11 (28.2)	5 (25.0)	6 (31.6)	
Other	2 (5.1)	0	2 (10.5)	
Smartphone access, n (%)	39 (100)	20 (100)	19 (100)	N/A
Internet access, n (%)	39 (100)	20 (100)	19 (100)	N/A
Time between visits (mo), median (IQR)				
Visit 1 & 2	4.8 (3.8-6.4)	4.9 (3.5-7.9)	4.8 (3.8-6.2)	.62
Visit 1 & 3	8.3 (5.6-10.2)	8.2 (5.8-11.8)	8.5 (5.6-9.0)	.65
Visit 2 & 3	2.4 (1.9-3.5)	2.3 (1.9-3.8)	2.4 (1.9-3.5)	.99

Abbreviations: IQR, interquartile range; N/A, not applicable.
[a]*P* values refer to comparisons between boys and girls. The 2-sample *t* test was used to compare age; Wilcoxon rank-sum test was used to compare time between visits; Pearson's χ^2 or Fisher's exact test was used to compare categorical variables.

Table 3
Primary Outcome: Asthma Control

A. cACT for 7-11 y old (n = 27)				
	All (n = 39)	Boys (n = 20)	Girls (n = 19)	*P* value[a]
Visit 1, mean (SD)	17.42 (3.68)	16.42 (3.48)	18.42 (3.75)	.14
Visit 2, mean (SD)	19.63 (2.81)	19.08 (2.39)	20.17 (3.19)	.38
Visit 3, mean (SD)	20.46 (2.70)	20.75 (2.63)	20.17 (2.86)	.61
Paired *t* test, unadjusted, mean difference (SE), *P* value				
Visit 2 vs visit 1	2.21 (.087)	2.67 (0.90)	1.75 (1.51)	
	$P = .02$	$P = .01$	$P = .27$	
Visit 3 vs visit 1	3.04 (.078)	4.33 (1.05)	1.75 (1.07)	
	$P < .001$	$P = .002$	$P = .13$	
B. ACT for 12 + y old (n = 12)				
	All (n = 39)	Boys (n = 20)	Girls (n = 19)	*P* value[a]
Visit 1, mean (SD)	16.45 (4.44)	14.83 (3.82)	18.40 (4.72)	.12
Visit 2, mean (SD)	21.55 (2.42)	21.50 (2.07)	21.60 (3.05)	.71
Visit 3, mean (SD)	19.64 (4.25)	21.83 (2.04)	17.00 (4.90)	**.02**
Paired *t* test, unadjusted, mean difference (SE), *P*				
Visit 2 vs visit 1	5.09 (1.53)	6.67 (2.03)	3.20 (2.25)	
	$P = .008$	$P = .02$	$P = .23$	
Visit 3 vs visit 1	3.18 (1.86)	7.00 (1.71)	−1.40 (2.23)	
	$P = .12$	$P = .01$	$P = .56$	
C. Asthma control (cACT and ACT), binary (n = 39)[b]				
Asthma control, n (%)	All (n = 39)	Boys (n = 20)	Girls (n = 19)	*P* value[a]
Visit 1	12 (30.8)	3 (15.0)	9 (47.4)	**.04**
Visit 2	21 (53.9)	12 (60.0)	9 (47.4)	.43
Visit 3	23 (59.0)	14 (70.0)	9 (47.4)d	.15
McNemar's test, *P* value				
Visit 2 vs visit 1	$P = .04$	$P = .003$	$P > .99$	
Visit 3 vs visit 1	$P = .02$	$P = .005$	$P > .99$	

Abbreviations: ACT, asthma control test; cACT, childhood asthma control test.
NOTE: Bold values indicate statistically significant values.
[a]*P* values in the last column refer to the comparisons between boys and girls using the 2-sample *t* test.
[b]Well-controlled asthma is defined as a cACT or ACT score of greater than or equal to 20.

These increases were seen in boys (15% vs 60%, $P = .003$; 15% vs 70%, $P = .005$), but not in girls (Table 3).

Significant correlations were only found between changes in asthma control and sex (visit 2 vs visit 1 (rho= −0.34, $P = .03$; visit 3 vs visit 1: rho= −0.40, $P = .01$). In addition, GLLM was used to assess the interaction effects on asthma control between sex and visits while adjusting for age, parental education, and time between visits. For visit 2 vs visit 1, the interaction effects on asthma control between sex and visits were significant ($P = .04$); the adjusted odds ratio (OR) of having asthma that is well-controlled is 9.00 among boys (95% confidence interval [CI], 1.78-45.7; $P = .009$) and 1.00 among girls (95% CI, 0.26-3.91; $P > .99$). For the visit 3 vs visit 1 comparison, the interaction effect was also significant ($P = .02$) with OR of having well-controlled asthma being 13.8 among boys (95% CI, 2.56-74.4; $P = .003$) and 1.00 among girls (95% CI, (0.26-3.92), P > .99).

Secondary Clinical Outcomes: Asthma Knowledge, Quality of Life, Health care Utilization

The mean AIRS-SR scores increased significantly from pre- to postintervention at baseline (3.55 vs 3.76, $P < .001$) (Table 4). AIRS-SR scores similarly increased from preintervention visit 1 to visit 2 (3.55 vs 3.80, $P = .001$) and visit 3 (3.55 vs 3.99, $P < .001$).

Lower scores on the NIH PROMIS PAIS questionnaire indicate improved asthma symptoms.[32,33] Patients reported statistically significant lower mean scores on the PAIS from visit 1 to visit 2

Table 4
Secondary Clinical and Process Outcomes

	AIRS-SR	PAIS	ED	Hospitalization	Prednisone	CSQ-8	Time spent (min)
A. Summary statistics at each visit, mean (SD) (n = 39)							
Visit 1 preintervention	3.55 (0.27)	-	-	-	-	-	-
Visit 1 postintervention	3.76 (0.35)	43.33 (13.35)	0.46 (0.91)	0.10 (0.38)	0.49 (0.91)	30.1 (2.2)	36.1 (8.6)
Visit 2	3.80 (0.32)	34.08 (11.07)	0.13 (0.41)	0 (0)	0.13 (0.34)	30.4 (1.8)	36.1 (6.5)
Visit 3	3.99 (0.37)	31.74 (12.26)	0.08 (0.48)	0.05 (0.32)	0.03 (0.16)	29.7 (3.8)	35.0 (6.7)
B. Paired *t* test, unadjusted, mean difference (SE)							
Visit 1: post vs preintervention	0.20 (0.05), $P < .001$	-	-	-	-	-	-
Visit 2 vs visit 1[b]	0.25 (0.07) $P = .001$	−9.26 (2.49) $P < .001$	−0.33 (0.14) $P = .03$	−0.10 (0.06) $P = .10$	−0.36 (0.14) $P = .02$	0.26 (0.39) $P = .51$	0.08 (1.48) $P = .96$
Visit 3 vs visit 1[b]	0.43 (0.08) $P < .001$	−11.59 (2.74) $P < .001$	−0.38 (0.16) $P = .02$	−0.05 (0.08) $P = .53$	−0.46 (0.15) $P = .003$	−0.44 (0.65) $P = .50$	−1.10 (1.58) $P = .49$
C. Linear mixed model, adjusted,[b] effect size (95% CI)							
Visit 1: post- vs preintervention	0.20 (0.09-0.31) $P < .001$	-	-	-	-	-	-
Visit 2 vs visit 1[a]	0.25 (0.12-0.38) $P < .001$	−9.26 (−14.30 to −4.21) $P < .001$	−0.33 (−0.62 to −0.04) $P = .03$	−0.10 (−0.23 to 0.02) $P = .10$	−0.36 (−0.65 to −0.07) $P = .02$	0.26 (−0.53 to 1.05) $P = .51$	0.08 (−2.93 to 3.08) $P = .96$
Visit 3 vs visit 1[a]	0.43 (0.29-0.58) $P < .001$	−11.59 (−17.14 to −6.04) $P < .001$	-0.38 (−0.71 to −0.06) $P = .02$	-0.05 (−0.21 to 0.11) $P = .53$	−0.46 (−0.76 to −0.17) $P = .003$	−0.44 (−1.74 to 0.87) $P = .50$	−1.10 (−4.29 to 2.09) $P = .49$

Abbreviations: AIRS-SR, asthma illness representation scale–self-administered; CI, confidence interval; CSQ-8, Client Satisfaction Questionnaire–8; ED, emergency department; PAIS, pediatric asthma impact scale.
[a]For AIRS-SR, paired *t* test and linear mixed model analysis, visit 1 refers to visit 1 preintervention measure.
[b]Linear mixed modeling was adjusted for baseline age, sex, parental education, and time between visits.

(43.33 vs 34.08, $P < .001$) and visit 3 (43.33 vs 31.74, $P < .001$), indicating improved quality of life.

On average, the number of ED visits decreased significantly from visit 1 to visit 2 (0.46 vs 0.13, $P = .03$) and to visit 3 (0.46 vs 0.08, $P = .02$). Prednisone use also significantly decreased from visit 1 to visits 2 and 3 (0.49 vs 0.13, $P = .02$; 0.49 vs 0.03, $P = .003$). The number of asthma-related hospitalizations was low at baseline (0.10 ± 0.38), and the changes between visits were not significant ($P \geq .10$).

The changes in all the secondary clinical outcomes were not significantly associated with baseline age, sex, parental education, and time between visits. When adjusting for these potential confounders by means of generalized mixed linear modeling, the conclusions still held true (Table 4).

Process Outcomes

Satisfaction with the application was high, as indicated by the mean CSQ-8 score of 30 out of the total score of 32 at each visit (Table 4). Satisfaction did not vary significantly between visits ($P \geq .50$). Patients spent 35 to 36 minutes on average on the intervention at each visit, with no significant changes in completion time between visits ($P \geq .49$).

Power Analysis

A sample size of 39 pairs achieves greater than 80% power to detect an increase of 28.2% (59.0% vs 30.8%) in the rate of controlled asthma from visit 1 to visit 3 using a one-sided McNemar's test with a significance level of .05. A sample size of 39 achieves 80% power to detect a mean difference of 0.5 SD unit in the continuous secondary outcomes from baseline to follow-up time points with a significance level (alpha) of .05 using a two-sided paired *t* test.

Discussion

There is a growing trend to develop digital health strategies for the management of pediatric asthma. Studies have found that adolescents were generally receptive toward asthma management applications but desired more engaging and educational content that would allow self-tracking abilities, promoting autonomy.[36,37] Text messaging–based platforms for asthma management led to improved quality of life and greater asthma management self-confidence in 2 separate studies.[38,39] A randomized controlled trial studying a web-based platform, consisting of educational activities and a self-logging system, led to decreased nighttime symptoms relative to baseline but not to the control arm and made minimal impact on health care utilization.[40] The kHealth system and Automated Device for Asthma Monitoring assist in remote monitoring gathering real-time data.[41,42]

Novel features of ASTHMAXcel Adventures include its gamified interface directed toward maximizing user retention, personalized algorithms to display relevant educational content, and other features to drive behavior change, including push notifications and an application leaderboard. Many of these features that comprise ASTHMAXcel Adventures were first discussed and reviewed with patients in the adult version of ASTHMAXcel and were regarded favorably in a focus group.[24,25] The importance of eliciting feedback from patients to craft a user-centered design has been stressed by direct interviews with adolescents and other larger studies that have suffered from marked user attrition rates.[18,36,37]

Overall, our study population was representative of the demographics of the greater Bronx population. The proportion of ethnic and racial minorities, multilingual speakers, and Medicaid coverage rates were similar to the overall Bronx population.[43,44] The large proportion of minority children that comprise our study is important, given the ethnic differences in asthma prevalence, morbidity, and mortality.[45] Children of black race are twice as likely to have asthma than children of white race, with high rates of daily

symptoms and health care utilization and minimal access to an asthma specialist or asthma plan.[46,47] The poor outcomes that disproportionately affect vulnerable minority populations require targeted interventions, such as ASTHMAXcel Adventures. In addition, even though approximately 27% of people in the Bronx do not have access to a broadband internet connection, all participants in our study had access to smartphones and the internet, supporting that interventions through mobile apps are viable, potentially equalizing opportunities for underserved populations.[13,43]

ASTHMAXcel Adventures was associated with an improvement in asthma control based on our primary outcomes, cACT and ACT. Notably, both metrics have maximum values of 27 and 25, thus, limiting the amount of improvement that can be shown by both tests. The cACT found considerable improvements at all visits past baseline, but scores were only statistically significantly increased at visit 2 relative to baseline for the ACT. This result can be partially explained by the score already approaching the maximum score by visit 2, limiting the amount of achievable improvement at visit 3. However, the proportion of patients that were well-controlled continued to increase at visit 3 (Table 3), suggesting that as the scores of these tests start approaching their maximums, it is important to consider the distribution of well-controlled scores among patients. In addition, the magnitude of improvement in cACT scores was less than in ACT scores. This improvement in cACT scores may not be clinically meaningful if a patient's baseline score is so low that after the intervention, it does not reach 20, indicating well-controlled asthma. This trend suggests that the intervention may potentially be more effective in older children but will need to be further evaluated in other studies.

When stratified by sex, these effects were magnified in boys and not observed in girls. The number of boys and girls in this study were approximately even, and there were no differences in baseline characteristics between sexes. One possible explanation may be the relatively small number of patients. Differing video game behaviors may provide an additional explanation. The number of adolescents that play any video game has been growing among all adolescents, including minorities, but the percentage of boys still outnumbers the girls (97% vs 83%).[12] We did not specifically ask regarding video game behavior in this study, but asking this question in future studies may yield more information.

Similar to the cACT and ACT, the NIH PROMIS PAIS evaluates asthma symptoms. The sustained improvements in asthma control, according to the PAIS score, supports the conclusions drawn from the cACT and ACT that ASTHMAXcel Adventures is associated with longitudinal improvements in patient-reported clinical outcomes.

The relationship between improved asthma knowledge through in-school education programs and improved clinical outcomes and decreased health care utilization in children has been established in several studies and summarized in a recent Cochrane review.[7] Another review of 12 studies of school-based educational programs, including both in-person and computerized interventions and focusing specifically on low-income, minority populations, found many to be effective in improving patient-reported asthma outcomes, self-management, and health care utilization.[6] Our findings indicating improvement in the AIRS-SR postintervention confirms the conclusions of previous studies, supporting the relationship between improved asthma knowledge and improved outcomes and decreased health care utilization.

Educational programs have been associated with decreased health care utilization, resulting in positive economic impacts.[8,9,48] The cost of a pediatric ED visit is estimated to be $1045.97 and pediatric inpatient admission to be $10,746.14.[9] Thus, reductions in asthma-related health care utilization can spare considerable costs. In our study, the reduction in ED visits and prednisone use was significant over time. Sparing unnecessary prednisone may mitigate adverse effects such as weight gain, which is also negatively linked with asthma outcomes.[49-51] Such reductions in health care utilization have specifically important effects within the context of our patient population with low household incomes and high poverty rates.[43] Furthermore, studies have established the importance of pediatric asthma control nationally, impacting health care costs, school days lost, adult absenteeism, and overall lowered productivity in all states.[3,4,52] The diminished productivity from premature asthma-related pediatric mortality results in more than $210 million lost annually.[52] Given the nearly universal access to smartphones among adolescents, the educational content on ASTHMAXcel Adventures should be easily accessible even in resource-limited areas.[12]

Patients were highly satisfied with the intervention. Our group strove to develop an engaging application viewed favorably by patients by means of gamification, given the high attrition experienced by several mHealth interventions and that typically 67% of the general population stop using an mHealth app after a single use.[18,53,54] Gamification has often been linked to health behavior change with 1 recent mHealth study reporting high retention rates.[14,55,56] To date, however, there have been few other asthma management applications that utilize gamification, making ASTHMAXcel Adventures novel in design. Another appealing aspect of this intervention lies in its convenience. In-person education is often limited to clinic settings, but mHealth applications may be used anywhere and used in smaller increments of time. The engaging gamified nature of the application may attract users resulting in multiple plays over time. In this study, participants were not able to use the intervention off-site, and thus we did not measure utilization metrics. Such metrics will be evaluated in current larger studies for longer periods of time, allowing us to ascertain long-term user retention.

ASTHMAXcel Adventures was associated with improvements in asthma knowledge, control, and symptoms and also decreased rates of ED visits and prednisone use. This intervention promotes behavior change in a user-centered experience through a novel, gamified interface. Available for free on iOS and Android app marketplaces, this intervention is accessible to most. Such an intervention has particular value in the current world climate as coronavirus disease 2019 has interrupted usual care for many patients. The Centers for Disease Control and Prevention and the American Lung Association have identified that those with asthma are at risk of developing severe respiratory infections.[57,58] The importance of telehealth and other remote care strategies have become increasingly recognized to avoid unnecessary in-person exposures.[59,60] Whereas ASTHMAXcel Adventures will have general utility in resource-poor settings, its application and potential are highlighted in the current pandemic.

This study has some limitations. The sample size is relatively small. We are currently validating the conclusions in a larger randomized controlled trial. In addition, this study was prospective but single arm only. We have no historical data on asthma outcomes, rendering us unable to compare our results with each patient's history as a control. Our ongoing randomized controlled trial is currently comparing its impact against a human educator or usual care and will focus on primary care settings to strengthen the external validity of ASTHMAXcel Adventures. In addition, there are other metrics that we could have evaluated to determine the efficacy of our intervention, including changes to treatment, compliance, or lung function tests over time. We plan to evaluate these metrics in future studies. Given that this study evaluated the impact of the intervention with on-site use only, the impact on behavior change cannot be completely elucidated. Our ongoing randomized controlled trial collects the same outcomes remotely without requiring on-site visits, allowing us to more accurately assess ASTHMAXcel Adventures in real-world settings. We also plan to monitor app utilization for a longer time period to assess user retention. Finally, we observed a difference when stratifying cACT

and ACT by sex only. Although this effect by sex was not observed in our other measures, we believe that a larger study population in future trials may help further evaluate this trend. We also plan on ascertaining baseline video game behaviors to confirm whether this may be influencing such effect. Future updates to the ASTHMAXcel Adventures app will also include Spanish translations to further increase accessibility to the educational content for non-English and multilingual speakers, mitigating the recruitment bias that may be present in our study.

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