Automated growth monitoring app (GROWIN): a mobile Health (mHealth) tool to improve the diagnosis and early management of growth and nutritional disorders in childhood

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ABSTRACT

Objective: To assess the functionality and feasibility of the GROWIN app for promoting early detection of growth disorders in childhood, supporting early interventions, and improving children's lifestyle by analyzing data collected over 3 years (2018–2020).

Methods: We retrospectively assessed the growth parameters (height, weight, body mass index [BMI], abdominal circumference) entered by users (caregivers/parents) in the GROWIN app. We also analyzed the potential health problems detected and the messages/recommendations the app showed. Finally, we assessed the possible impact/benefit of the app on the growth of the children.

Results: A total of 21 633 users (Spanish [65%], Latin American [30%], and others [5%]) entered 10.5 ± 8.3 measurements (0–15 y old). 1200 recommendations were for low height and 550 for low weight. 1250 improved their measurements. A specialist review was recommended in 500 patients due to low height. 2567 nutrition tests were run. All children with obesity (n = 855, BMI: 27.8 kg/m^2 [2.25 SD]) completed the initial test with a follow-up of ≥1 year. Initial results (score: 8.1) showed poor eating habits (fast food, commercially baked goods, candy, etc.), with >90% not having breakfast. After 3–6 months, BMI decreased ≥1 point, and test scores increased ≥2 points. This benefit was maintained beyond 1 year and was correlated with an improvement in BMI (r = -.65, P = .01).

Discussion/Conclusions: The GROWIN app represents an innovative automated solution for families to monitor growth. It allows the early detection of abnormal growth indicators during childhood and adolescence, promoting early interventions. Additionally, in children with obesity, an improvement in healthy nutritional habits and a decrease in BMI were observed.

Key words: mHealth application, digital technologies, early diagnosis, growth monitoring, obesity, prevention

BACKGROUND AND SIGNIFICANCE

Growth disorders are health problems that prevent children from developing a normal height and weight. These problems include, among others, obesity (body mass index [BMI] >95th percentile), overweight (BMI > 85th percentile), and short stature (height < −2 standard deviation [SD]).

The diagnosis of growth disorders is frequently delayed despite the monitoring of linear growth to support their early detection and timely treatment.[1] Social barriers, difficulties recognizing the problem, the wide range of underlying causes, and the lack of knowledge of the phenotypic spectrum of each condition make this early diagnosis difficult for children referred to physicians, both due to short stature and childhood obesity.[2,3]

Early intervention in growth disorders is critical due to the negative consequences they can promote. For example, childhood obesity (mainly weight status from 2 to 6 y) is well-established as a strong predictor of adult obesity/overweight[4] that negatively impacts health status. Moreover, there are situations where late intervention is no longer as useful; for example, in short stature due to growth hormone deficiency, a delay in the intervention reduces the possibility of attaining their normal height potential.[5] Therefore, any tool that could aid diagnosis and facilitate early intervention would be very useful.

The potential of digital technologies (eg, mobile health [mHealth]) to improve public health has already been recognized by the World Health Organization (WHO).[6] Their use can benefit patient care, health strategies, and initiatives.[7] Moreover, it may be a promising approach due to the widespread use of mobile electronic devices (smart devices).[8] In the case of growth disorders, automated growth monitoring with algorithms integrated into electronic health records can enhance early detection, possibly achieving a higher rate of referrals to specialists and a greater diagnostic yield.[1]

New digital technologies in the pediatric endocrinology setting allow efficient and precise assessment performance.[9] Height measurements outside the clinic could increase the frequency of these evaluations and provide signs of growth failure to support earlier intervention.[10] Moreover, in addition to early diagnosis, internet or telephone-based interventions have been reported to be effective in improving BMI and weight loss or increasing physical activity in obese adults.[11] The use of mHealth (mobile devices) for the treatment of overweight and obesity in children is still new, but, despite the limited evidence available, it has shown to be promising,[8] and it has piqued the interest of specialists.[12]

Considering all the above and that the published literature shows content of apps/digital technologies designed to record children's growth data,[13,14] mainly focused on short stature and the use of human growth hormone therapy,[15,16] but without offering advice/recommendations based on that data to improve it, we developed the GROWIN application (app). It was designed to help follow up children's growth by offering personalized tips for healthy living. The objectives of this app are to support families during their children's growth and development, identify growth disorders and overweight/obesity problems (before they manifest themselves), and provide automatic recommendations adapted to the patient's needs. In addition, it aims to empower families to make positive behavioral changes (mainly in feeding practices and physical activity) and improve their lifestyles. To the best of our knowledge, this is the first publication that shows retrospective data analysis on outcomes after using an app designed to measure child's growth and identify disorders, but also providing personalized recommendations.

OBJECTIVES

We describe the functionality of the GROWIN app and present our experience and outcomes over 3 years, focusing on the early detection of abnormal growth and early interventions.

This retrospective analysis aimed to test the utility and feasibility of the GROWIN app for promoting early detection of growth disorders in childhood, supporting earlier interventions, and improving the children's lifestyle.

MATERIALS AND METHODS

Functionality of the GROWIN mHealth application

The aim of the GROWIN app, a phone app, was to offer families a new way of monitoring children's growth from 0 to 18 years old. Since its market launch in 2017, the GROWIN app has been free of charge. It was available in Spanish and English for both iOS and Android until 2020, and only available for Android afterward (although people with iOS who have already downloaded it can continue using it). It was presented in Spanish pediatric endocrinology meetings and to the Spanish Association of Pediatrics (AEP) so that pediatricians could get to know it and present it to their patients. Additionally, it was advertised in the national press and radio to the overall population.

GROWIN was designed by the endocrinology service of Hospital Miguel Servet (Spain) and developed by eHWin New Technologies. It was supported by the AEP (by its Spanish acronym) and the Spanish Association of Primary Care Pediatrics (AEPap, by its Spanish acronym) and approved by the Clinical Research Ethics Committee of Aragón (CEICA). It was funded by MERCK.

After downloading the app, families should register each child and add some initial data: name; gender; data at birth (birth date, weeks of gestation, height [cm], weight [kg], country, and region), parents' height (cm) in order to calculate the height potential and find out the growth potential, and the use of concomitant treatments that can influence growth and weight, such as corticosteroids or methylphenidate.

Depending on their geographical location, the app automatically selects a reference population to calculate percentiles, drawing data from the Spanish,[17] WHO,[18] Centers for Disease Control and Prevention (CDC),[19] and Argentinian[20] studies that are entered in the app. However, users, pediatricians, or endocrinologists can also manually select another study.

Families should enter their children's growth parameters as they grow: height, weight, and abdominal circumference. BMI is calculated by the app. The data entry was left entirely up to the discretion of each user. These 4 values are displayed in different graphics showing their percentiles and evolution. The illustrations make it easier for families to understand the results (Figure 1).

Each time a user enters data, the app uses an automated growth monitoring strategy incorporating a scientific mathematical validated algorithm[21,22] to predict the next measurement (weight, height, and BMI 2–4 mo later) if everything continues the same. These values are predicted based on the normality values of the different studies concerning weight, height, BMI, and abdominal circumference gain during the different stages of childhood.

Additionally, the GROWIN app's design includes a logistic regression study with auxological parameters and predictive models of the risk of developing obesity.[21,22] Two validated logistical regression models are used for the prediction; one model for the risk of developing obesity in the future and other for the measurements

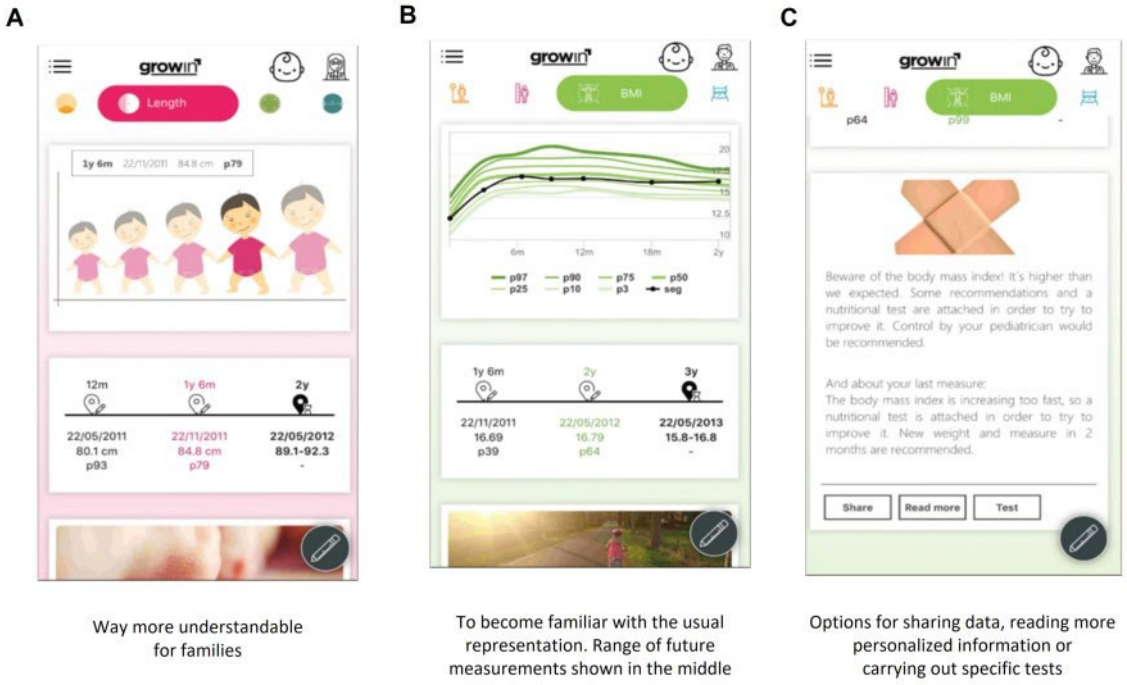


Figure 1. Appearance of the different app screens. (A) New way of representing percentiles. (B) Usual representation of percentiles. (C) Personal recommendations.

(weight, height, BMI, and abdominal circumference) after 3–6 months of the current measurement. A complicated model to use (with many variables), and another simpler and more reproducible model than those described by de Arriba Muñoz et al[21] and Morlan Herrador et al,[22] which required multiple measurements, including unusual parameters such as fat folds.

The app's models use z-scores (number of SD away from a reference median/mean) for the prediction; changes in 0.5 SD in any parameter trigger a response. Responses are triggered by a value outside of a specific range (weight, BMI or abdominal circumference >85th percentile, when weight or height are < -2 SD or when there is an increase or decrease in a value >0.5 SD; Table 1). This design enables the prediction of both disorders (obesity and overweight).

Each time data are entered, the app automatically displays 2 messages/recommendations based on the parameters' SDs and their predicted values: one regarding the current status and the other one considering its change since the last entered value.

If any SD value is outside the recommended ranges, a recommendation is displayed, which was made by pediatric endocrinologists and incorporated into the app. The app incorporates 6000 potential recommendations. Some recommendations are based on the child's age, because the growth at different ages (0–18 y) is completely different, and there are also recommendations based on the birth weight because the growth of adequate or small for gestational age (SGA) children is different. Moreover, there are messages/recommendations for children with no growth problems to send good habit reminders, with new customized tips and advice about nutrition, fitness, and healthy living reported in a very simple and familiar manner. Table 1 shows an example of how recommendations are selected based on the children's age and the SD of weight value.

The aim of these messages/recommendations is to monitor the child's evolution closely and prevent health problems related to small weight at birth (SGA children),[23] obesity and overweight, low weight, or growth disorders.

When the app analyzes the data included by the users and the results deviate from those predicted and it interprets that a health problem is objectively likely to occur (major growth disorders, low weight, obesity, or overweight), then, 3 options appear at the bottom of the screen (Figure 1C).

One option ("Share") is to download the data into a spread sheet and share them with anyone via social networks, email, or the physician. This possibility is available at any time, allowing the user to share the information with their pediatrician and resolve any doubts that may arise. The second option ("Read more") includes additional and more extensive recommendations adjusted to the children's age. Finally, the third option ("Test") leads to an easy-to-complete questionnaire to assess their eating habits (if a tendency to gain weight dangerously or overweight/obesity is detected) or physical activity. The questionnaires data were collected 3 timepoints. When the health problem is predicted (baseline), after 3–6 months and after year (12 mo). According to the responses provided, customized/personalized recommendations are automatically sent to improve the items accordingly (eating habits or physical activity, as required).

The nutrition questionnaire used is the Quality Test of the Mediterranean Diet (MD) in Childhood and Adolescence.[24,25] It measures the adherence of the child's diet to the MD (considered nutritionally correct). The questionnaire consists of 16 questions that are answered/selected only if the statement corresponds to the child's behavior (Table 3). The first 12 questions (related to good habits) score positively (+1), and the remaining 4 questions (related to bad habits) score negatively (−1). Therefore, the best possible score is 12.

The score determines the child's diet quality: low (<3), fair (4–7; needs adjustment), and optimal (>8). A higher score indicates a better diet.

Table 1. Organization of the messages/recommendations launched by the app based on the children's age and SD value of weight measurements

	Age ranges (y)												
SD of weight value	0–0.5	0.5–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
≥ +2.5	6	6	6	6	1	1	1	2.1	2.1	2.1	2.1	2.1	2.1
(+2.0, +2.5)	6	6	6	6	1	1	1	2.1	2.1	2.1	2.1	2.1	2.1
(+1.5, +2.0)	6	6	6	6	6	6	6	6	6	6	6	6	6
(−1.5, +1.5)	6	6	6	6	6	6	6	6	6	6	6	6	6
(−2.0, −1.5)	6	6	6	6	6	6	6	6	6	6	6	6	6
(−2.5, −2.0)	10	10	13	10	8	8	8	9.1	9.1	9.1	9.1	9.1	9.1
≤ −2.5	10	10	13	10	13	10	10	9.1	9.1	9.1	9.1	9.1	9.1

ID	Message/Recommendation
1	The weight is above what is desired Send appendix[a] + Questionnaire[b] + recommendations according to questionnaire[b] + weight and measure again in 3 mo, if weight >2DS and BMI >+2DS we recommend assessment
2.1	Be careful with the weight, it is above what is desired Send appendix[a] + questionnaire[b] + recommendations according to questionnaire[b] + we recommend assessment by your pediatrician
4.16	During this period, it has gained more weight than desired We recommend send appendix[a] and reweigh in 1 mo. If weight >+2 SD, questionnaire + recommendations according to questionnaire results and reweight and measure in 2 mo. If weight >+2 SD and BMI >+2 SD we recommend assessment by Pediatrician
8	The weight is below what we would like Increase the number of feedings per day or the amount per feeding, reweight in 1 wk
9.1	The weight is below what we would like Add cereals to the milk or increase the amount, add olive oil and potato to the purees and reweight in 1 wk
10	The weight is below what we would like We recommend an evaluation by your pediatrician
11.1	In this period, he/she has gained less weight than expected
5.1	The weight in this period has changed normally, but it is necessary to monitor it, try to reduce the amount of food, eat only 4 main meals, do not exceed 500–600 mL of dairy products per day, do not offer sweetened beverages
5.2	In this period of time, he has gained a little more weight than desired. Watch the amount of food, cut down on portions, and sugary drinks
6	Ok: your weight is perfect, good situation, keep it up!!!
6.1	The weight gain was adequate, congratulations!

Abbreviations: MD: Mediterranean diet; SD: standard deviation.

[a]Appendix: more complex recommendations sent based on the specific situation.

[b]Questionnaire: MD Quality Questionnaire.

The app displays the following messages/recommendations based on the score of the Quality Test of the MD in Childhood and Adolescence; >8: "CONGRATULATIONS! Your diet is optimal"; 4–7: "We think you need to improve your nutrition"; <3: "YOU NEED to improve your nutrition."

In failed questions, a recommendation was launched aimed at improving the habit it addresses. Moreover, physical activity was promoted (personalized recommendation based on the age of the children): climb the stairs, play sports, avoid spending more than 1 hour in front of a screen, and NO more than 2 h a day watching television or playing video games.

There is no specific questionnaire if the potential problem is related to physical activity, although there are individual questions and recommendations. According to the evolution of the risk of becoming overweight/obese, users are asked about the frequency (d/wk and h/d) and intensity (light–moderate–strong) of the physical exercise children do as well as the number of hours of screen/technology use per week. According to their answers, they are sent recommendations advising them to increase the number and intensity of daily exercise and to decrease the number of hours of screen use.

When the recommendations do not bring about improvements and/or there is evidence of growth, underweight, or obesity problems, the app recommends a visit to a specialist doctor or pediatrician.

The company EHWIN NEW TECHNOLOGIES SL is the holder, data controller, and data processor of the data that the user enters into the mobile app. After the data are entered, they are encrypted and transferred to the central database (located in the cloud and protected in compliance with the entire Data Protection Act for storage purposes). The names and identifiers of the users and their children are coded (pseudo-anonymized) according to European Directive 95/46/EC.

Data analysis

A general description of the total sample (users/children) was made based on the region to which they belong and their birth weight for gestational age (first objective: early detection of growth disorders). A study of the normality and homoscedasticity of the data was carried out using the Kolmogorov-Smirnov and Levene tests, respectively. Categorical variables (sex, adequate for gestational age (AGA), or SGA, country, percentage of affirmative [YES] and negative [NO] responses of the 16 items of the Quality Questionnaire of the MD in Childhood and Adolescence) were described as the number of cases in each category and percentages referred to the whole study population. Continuous variables (age, BMI, and mean of the results of the Quality Questionnaire of the MD in Childhood and Adolescence) were described as a mean ± SD.

For all statistical studies, the app's model use z-scores; the values of the parameters (weight, height, and BMI) have been used in SD instead of absolute values that would prevent us from making comparisons between subjects of different ages or sexes. The large difference between the absolute values of ages and sexes prevents these parameters from being analyzed together. In order to be able to make these comparisons, regardless the age or gender, absolute values are converted into the value of the SD (value referenced according to the population mean).

Variables were compared with the Student's t test (second objective: supporting earlier interventions). Paired data were analyzed with paired Student's t test to compare quantitative variables (third objective: improving the children's lifestyle): (1) the responses of the 16 items evaluated in the nutrition questionnaire (initial, at 3–6, and 12 mo) and assess whether the recommendations launched by the app promote an improvement in the eating habits and (2) the BMI (SD) to evaluate if the improvement in the eating habits was associated with an improvement in BMI values. Paired Student's t test was used to analyze differences in the same subject over time: the change in the results for each subject, thus assessing whether there is improvement.

The statistical analysis was performed using SPSS software, version 21.0 for Windows. Two-sided P values were obtained, and statistically significant results were declared if $P < .05$. The 95% CI for the mean difference was based on an asymptotic method.

Ethics and consent process

The app includes a privacy policy that explains how sensitive user and device data are treated. Users must accept this policy before using the app.

By entering their data, users give their consent to the holder/data controller to process the data for the purpose, among others, of conducting academic studies based on such contents.

RESULTS

App users

This app was downloaded by 21 633 users from January 1, 2018, to December 31, 2020. Most were from Spain (14 061), although 6490 users were from Latin America (LATAM), and 1052 users from other countries also downloaded it, among which the United Kingdom stands out. Figure 2 shows the geographical distribution of the users.

Overall, 90% of the users used the app regularly and frequently entered data during the 3-year period analyzed (95%, 86%, and 83% in the children's age subgroups of 0–5, 6–10, and 11–15 y, respectively). Only 10% of those who downloaded the app were not "active" users (5%, 14%, and 17% in the children's age subgroups of 0–5, 6–10, and 11–15 y, respectively). An active user is defined as a user who has entered at least 4 data per year during the first 2 years of life and at least 2 data per year after the age of 2 years.

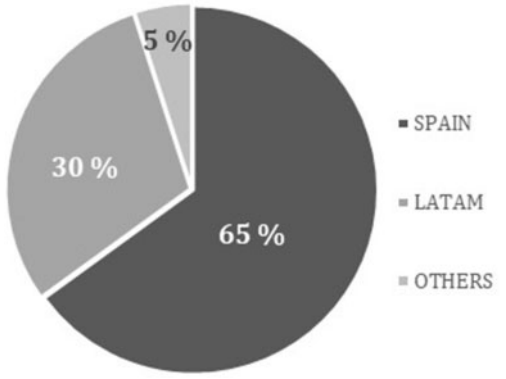
Most data were entered outside the period of usual child's routine doctor's appointment.

Data entered in the app

Among the users who downloaded the app during this 3-year period (2018–2020), 20% did so when their child was born and 80% (17307 patients) after the birth of the child. Of the latter, 15141 patients (70% of the total users), entered retrospectively the data from birth until downloading the app (at a mean age of 6 y; range 0.5–15 y) and then those obtained thereafter. The remaining patients (10% of the total users) entered data since the unloading (at a mean age of 3 y; range 0.1–12 y), but did not add any previous information.

Thirty-four point four percent of users (n = 7442) entered the data of 2 children. Therefore, data were collected from 29 075 children. Table 2 shows the basal characteristics of the children whose data were entered in the app by the users.

The age of the children for whom users entered data in the app ranged from 0 to 15 years old (Table 2). At birth, 7.3% of the children were SGA, 89.5% were AGA, and 3.2% were large for gestational age (LGA; Table 2). No differences between regions in the percentage of children AGA, LGA, and SGA were observed.



CHILDREN CHARACTERISTICS (N= 29,075)

	Age*, years mean (SD)	Sex (%) Male	Female
All regions	2.3 (5.8)	44	56
Spain	2.2 (5.5)	45	55
LATAM	3.5 (6.6)	40	60
Others	3.1 (3.5)	48	52

**At the time of first data entry*

Key: LATAM: Latin America; SD: standard deviation

Figure 2. Geographic distribution of the users of GROWIN app (2018–2020) and characteristics of the children for whom they entered data in the app.

Table 2. Main characteristics of the total sample (children for whom users entered data in the app; $n = 29\,075$)

Basal characteristics	
Sex; *n* (%)	
Male	12 793 (44)
Female	16 282 (56)
Mean gestational age, wk (SD)	38.3 (3.7)
Mean weight at birth, g (SD)	3275.3 (267)
Mean length at birth, cm (SD)	49.2 (3.4)
LGA, *n* (%)	930 (3.2)
AGA, *n* (%)	26 022 (89.5)
SGA, *n* (%)	2123 (7.3)
Children's age groups; *n* (%)	
0–5 y	14 101 (48.5)
6–10 y	10 554 (36.3)
11–15 y	4420 (15.2)

Abbreviations: AGA: adequate for gestational age; LGA: large for gestational age; SGA: small for gestational age; SD: standard deviation.

Users entered a mean of 10.5 6 8.3 measurements (11.9 6 6.3, 10.3 6 5.4, and 6.7 6 3.1 in the children's age subgroups of 0–5, 6–10, and 11–15 y, respectively; range of 1–47). The mean of measurements in case of active users was (14 6 5.2 [range of 10–47]). Most measurements belong to young children (first year of life). Data of older children were entered mainly when they had weight or height problems. Abdominal circumference (not measured at routine pediatricians' examinations) was the least included measurement in the app, only added 15% of the times that users enter data.

App interventions

Most (91%) of the messages/recommendation displayed by the app were positive (ie, recommendations for maintaining a healthy lifestyle). They reinforced users' habits and encouraged them to continue along the same path.

The app displayed recommendations for improving dietary and physical exercise habits due to low weight or low height for 1750 children (1200 [69%] due to low height and 550 [31%] due to low weight).

We observed an improvement in the next children's measurements 3–6 months after most of the recommendations ($n = 1250$of weight, $P = .01$). In the remaining 500 recommendations (for 500 subjects; all due to low height) measurements were not improved and then the app recommended a visit to the pediatrician or pediatric endocrinologist.

The app ran a total of 2567 initial nutrition questionnaires. When a growth problem was identified (baseline situation), 855 (33%) were due to obesity, 1239 (48%) due to overweight, and 473 (18%) due to an observed tendency to develop overweight and then obesity if the children continued along the same path. These initial nutrition questionnaires were completed by all the children with obesity (855/855; 100%); however, they were not completed by 112/473 (23.6%) children with a tendency to develop overweigh tand obesity, and by 163/1,239 (13.2%) overweight children. However, the children who did not complete the questionnaires kept using the app.

Table 3 shows the results of the initial tests (baseline situation) completed by the children with obesity and the ones completed during the follow-up (3–6 and 12 mo later). Among the 855 children with obesity at baseline (41.7% male; age [mean (SD), 11.8 (3.1) y]), 410 were from Spain (3% of the Spanish children in the app; 40.2% male; age [mean (SD), 12.9 (2.8) y]), 415 were from LATAM (6.5% of the Latin American children; 42.2% male; age [mean (SD), 10.1 (3.7) y]) and 30 were from other countries/regions (2.5% of these population; 53.3% male; age [mean (SD), 11.8 (3.1) y]).

The average BMI of the children for whom tests were completed was 27.8 kg/m^2 (2.25 SD), with a test score of 8.1. Table 4 shows the data according to the distribution of children. Three to six months after receiving advice from the app, an improvement in BMI (a decrease ≥1 point) and in the Quality Test of the MD Score (an increase ≥2 points) were observed (Table 4). The items that improved the most after the intervention (recommendations) were those related to the intake of fruit every day, vegetables, and dairy products, as well as the items on breakfast habits and the daily intake of candy, commercially baked goods, and fast-foods.The benefit in the scores was maintained beyond 1 year of follow-up (Table 4) and correlated with an improvement in the BMI ($r = -.65$, $P = .01$)

Table 3. Percentage of questions of the nutrition assessment answered in the affirmative by children with obesity ($n = 855$) at the initial questionnaire completion (baseline situation) and 3–6 and 12 months later

		Questionnaire of the MD in Childhood and Adolescence	Answers (%)					
			Baseline ($n = 855$)	3–6 mo ($n = 855$)	Change from baseline	12 mo ($n = 855$)	Change from baseline-	P^a value
Good habits	1	Do you eat a piece of fruit or drink fruit juice every day?	81.2	83.0	1.8	82.5	1.3	NS
	2	Do you eat a second piece of fruit every day?	40.6	75.2	34.6	74.0	33.4	.00
	3	Do you eat fresh (salads) or cooked vegetables once a day?	60.4	69	8.6	70.2	9.8	.01
	4	Do you eat fresh or cooked vegetables more than once a day?	25.0	62.3	37.3	60.7	35.7	.01
	5	Do you eat fresh fish regularly (at least 2–3 times per week)?	53.1	61.0	7.9	63.2	10.1	.03
	6	Do you like pulses and eat them more than once a week?	71.0	70.5	−0.5	70.1	−0.9	NS
	7	Do you eat pasta or rice almost daily (at least 5 days a week)?	36.4	50.8	14.4	50.5	14.1	.02
	8	Do you eat cereals or related products (bread, toast, etc.)?	63.0	61.8	−1.2	61.2	−1.8	NS
	9	Do you eat nuts regularly (at least to 3 times a week)? "Nuts are not recommended in children under 6 y old"	24.0	35.2	11.2	32.6	8.6	.04
	10	Do you use olive oil at home?	87.5	88.0	0.5	89.6	2.1	NS
	11	Do you consume dairy products for breakfast (milk, yogurt, etc.)?	52.1	67.2	15.1	65.6	13.5	.03
	12	Do you consume 2 yogurts and/or 40 g of cheese every day?	75.0	87.4	12.4	87.0	12	.04
Bad habits	13	You eat in fast-food restaurants (hamburgers, pizza…) at least once a week.	87.0	85.0	−2	88.2	1.2	NS
	14	You don't have breakfast	91.6	51.7	−39.9	53.5	−38.1	.01
	15	You usually eat commercially baked goods at breakfast	84.4	62.3	−22.1	65.0	−19.4	.02
	16	You eat candy every day	94.8	44.8	−50	48.5	−46.3	.01

Abbreviation: NS: not significant.
[a]Between baseline values and 12 months

DISCUSSION

Main findings

We present our experience and analysis of the data collected with the mHealth app GROWIN during a 3-year period (2018–2020). This app facilitates automated growth monitoring in children and screening of growth disorders by using a scientific-mathematical algorithm and creating predictive models of the risk of developing obesity.

The users of this app (n = 21 633) were mainly from Spain (65%), likely due to the app being only advertised in Spain. The users were parents or caregivers of children with ages ranging from 0 to 15 years old. The fact that the data belong to children up to 15 years of age would suggest that parents are less concerned when their children are older and have finished or are about to finish their growth. In fact, it has been previously reported that caregivers of children <6 months are more likely to regularly use a mobile app for growth monitoring than those with children >6 months.[26]

Parents' concern for their children's development could also be reflected by the frequency they enter data. Most (90%) were active users entering data, with only 10% of the users' missing data from before they downloaded the app.

Furthermore, users entered a mean of 10 measurements during the 3 years under study, showing continued use after installation, contrary to previous publications regarding the short time that most mHealth apps are used.[27] This continued use by caregivers, even without reminders (eg, with short message service) as reported in other mHealth technologies on up- take of routine growth monitoring,[28] and the fact that most of the data entry were outside the period of standard well-child checks (children's routine doctor's appointments) also reflect the ease of use and the utility of the GROWIN app as a source for additional data. All this can contribute to the early detection of growth and nutritional disorders by providing additional measurements, as the linear growth monitoring of apparently healthy children as a screening strategy can detect early indications of serious conditions, establishing weight status (underweight, normal weight, overweight, and obesity), and identifying short stature.[9,29]

In line with observations on the overall population concerning weight for gestational age (in European countries, there is a 10% prevalence of children who are born SGA or LGA),[30,31] most of the data (89.5%) entered in the GROWIN app belong to children who were AGA. In addition, data included belonged mainly to children with an adequate growth (height and weight), with a much lower percentage of children with low height/weight or overweight/obesity.

Table 4. Scores and BMI of children with obesity for whom a nutrition questionnaire was completed (*n* = 855)

		Baseline	3–6 mo	*P* value[b]	12 mo	*P* value[b]
Overall (*n* = 855)	BMI, mean (SD)	27.8 (2.25)	26.9 (2.05)	.01	26.2 (1.90)	.01
	Questionnaire[a]	8.1	10.2	.03	10.1	.02
Spain (*n* = 410)	BMI, mean (SD)	27.5 (2.2)	26.7 (1.98)	.01	26 (1.87)	.01
	Questionnaire[a]	8.6	11.1	.03	10.5	.02
LATAM (*n* = 415)	BMI, mean (SD)	28.2 (2.33)	27 (2.1)	.01	26.4 (1.95)	.01
	Questionnaire[a]	7.5	9.3	.03	9.8	.02
Others (*n* = 30)	BMI, mean (SD)	27.9 (2.27)	27 (2.1)	.01	26.3 (1.93)	.01
	Questionnaire[a]	8	9.5	.03	10	.02

Notes: Child's diet quality based on test scores: low (<3), fair (4–7; needs adjustment), and optimal (>8). A higher score indicates a better diet.
Abbreviations: BMI: body mass index; LATAM: Latin America; MD: Mediterranean diet.
[a]Quality Questionnaire of the MD in Childhood and Adolescence.
[b]Change from baseline.

This finding can also be justified by the previously reported low prevalence of growth disorders, 5.9%–13.4% in children with automated growth monitoring.[32]

With data from at least 29 075 children, the GROWIN app identified 1750 children with low weight or low height and provided recommendations for them. A potential reported reason for a delay in growth and development is a very low nutrient intake.[33] When this situation is detected, nutritional rehabilitation (increase in both caloric and protein intake) can enable catch-up growth.[34] In this sense, the recommendations provided by the GROWIN app on nutritional issues could help to improve the follow-up of overweight/obese patients. Eventually, only 500 recommendations promoted a visit to a physician (all due to low height) for the review of pathological conditions associated with the growth failure. The early diagnosis of short stature can be established during these visits, avoiding a delay that is extremely frequent in growth disorders (eg, Turner syndrome, celiac disease, and growth hormone deficiency).[32]

Early diagnosis leads to early and appropriate therapy, which has an optimal effect on growth and final height and prevents or diminishes complications, and could, therefore, result in a better quality of life.[29,35] The findings obtained with the GROWIN app and its recommendations show the potential of the new digital technologies to get greater standardization and automatization of height monitoring in children, improving the accuracy of referrals to specialists.[9] This potential benefit can justify the design of similar app, such as the presented by Thaventhiran et al[36] in the Society for Endocrinology BES 2021, that enables families to measure the UK child's height including alerts to facilitate early referral/diagnosis of growth disorders This reflects the trend to use this type of apps, being GROWIN more complete (not only height monitorization and with recommendations for improving the measures). With the availability of this kind of app (e-growth monitoring) for electronic devices, height measurements can be performed outside the clinic and with increased frequency, even in places with limited access to pediatricians; this can promote the detection of signs of short stature and support earlier intervention.[10] This can be also applied to weight monitoring.

Regarding excess weight in children, the app ran a total of 2567 nutrition tests: 855 due to obesity, 1239 due to overweight, and 473 due to an observed trend toward overweight and potential obesity. Currently, social changes have modified nutritional and physical activity habits, promoting an energy imbalance that leads to overweight and obesity.[37] Globally more people are obese than underweight, with 39 million children (5 y old) with obesity in 2020.[38] This supports the GROWIN app's findings of more frequent (1.5 times higher) excess weight than underweight/short stature in children.

Our analysis focused on children with obesity (*n* = 855) because it was the subgroup with more questionnaires answered, probably because families show more interest when their children are more affected. Our data showed a higher percentage of children with obesity in LATAM (6.5%) versus Spain (3%) or other locations (3%). However, this result must be interpreted cautiously and cannot be generalized due to the small number of users per region. In fact, this finding is not in concordance with the estimated proportion of children with obesity recently published by Di Cesare *et al*.[39] In this publication, the proportion of children with obesity aged between 2 and 4 years old is similar between high-income countries and LATAM and the Caribbean; on the contrary, this proportion is higher in high-income Western countries in the age range from 5 to 19.[39]

The initial mean score of the Quality Test of the MD in Childhood and Adolescence filled in by children with obesity was 8.1, just on the lower end of the threshold to require diet adjustments. Responses showed low compliance with some of the characteristics of the MD,[40] specifically the high intake of vegetables and fruits, the moderate consumption of fish, and the low intake of candy. All the items related to poor dietary habits showed the highest percentage of answers, with more than 90% of the children not eating breakfast.

The MD encourages healthy eating,[41] and adherence to its principles is recommended to combat obesity (among other chronic diseases).[37] Therefore, one of the aims of the recommendations provided by the GROWIN app was to improve nutritional habits. The 2-point increase in the test score reflects the positive impact of the recommendations, with the most improved items the intake of vegetables, fruits, and dairy products. Moreover, improvements were also observed in breakfast habits and in the reduction of the intake of candy, baked goods, and fast food. A decrease in BMI was significantly correlated with the improvement of test scores. These achievements corroborate the previously reported usefulness of telemedicine interventions to improve BMI and control weight in adults[11] and teenagers.[37]

There are publications on the promising results of smartphone-based mHealth interventions to promote physical activity in adults.[42] The GROWIN app already includes customized tips and advice about fitness, but, in the future, it could be improved with the addition of remote monitoring of the child's physical activity using wearables (body-worn devices, such as smartbands and smartwatches).

Physical activity monitoring would enable the estimation of calories burned by each physical activity recorded and enable personalized recommendations to be displayed in the app. The appropriate validation method/study for wearables assessing physical behavior has not yet been established.[43] However, this strategy has already been used to remotely monitor patients' physical activity remotely in adult patients pre and post bariatric surgery via the Moves app.[44,45] Moreover, this type of physical activity monitoring device has shown good tolerability in children and led to high compliance.[46]

In this study, with retrospective data analysis on outcomes, we demonstrate the potential of digital technologies (mHealth) to improve public health—a potential already recognized by the WHO[6]—but, this time, focusing on growth monitoring in children. Additionally, our data show that growth monitoring can provide primary overweight/obesity prevention and healthy behavior counseling opportunities. These early interventions have been described as more effective than weight management interventions after established weight problems.[29] An additional benefit of the GROWIN app is facilitating communication between parents/caregivers and doctors/health providers. With the "Share" option, data can be shared with the physician (by email). With this communication channel, parents can share the findings (concerns), and physicians can promote an intervention adapted to the needs of the children. This could imply a further step toward achieving growth monitoring apps that could provide an excellent channel for potential future intervention in childhood health.[14]

Limitations

The distribution of users was uneven, and the sample was small in each area, meaning no zone-specific conclusions could be drawn. However, the overall conclusion shows the app's usefulness, regardless of the area to which the user belongs.

Another limitation that should be considered is possible measurement errors as measurements were carried out by the parents and/or caregivers at home, and it is not possible to ensure data quality. Height is more difficult to measure than weight, which can be measured using a scale. Nevertheless, this possible error is mitigated by the large amount of data available, and the parents entered an average of 10 measurements for each child, making these measurements more reliable. Moreover, if an erroneous measure that entails a very abrupt change is entered, the app would send many recommendations that make users aware of the error, and they can delete it and reenter the correct data.

Another possible limitation of the data analysis is the lack of a control arm to assess the impact of GROWIN app use. Finally, despite the app displaying more than 500 recommendations to visit a pediatrician, we cannot determine whether these children actually went to the consultations.

CONCLUSIONS

The use of the GROWIN app allows the early detection of indications of abnormal growth (low weight/height or overweight/obesity) in children and adolescents, promoting early interventions. Among children with obesity, after receiving recommendations from the app, an improvement in healthy nutritional habits and a decrease in BMI were observed. For this reason, GROWIN represents an innovative solution for families to monitor growth and supports the provision of personalized medical care with individualized advice, which can lead to positive changes and healthy living habits. Moreover, it can provide a new collaborative mHealth network between parents/caregivers and doctors

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AUTHOR CONTRIBUTIONS

AAM and IMR designed and directed the Project and developed the scientific mathematical algorithm. AAM, MDC, IMR, and JIL designed and performed the app. AAM, IMR, MTGC, and ABO have developed the design of the app. AAM, MDC, MTGC, and ABO have carried out data analysis. AAM, MTGC, MDC, ABO, IMR, and JIL contributed to the writing of the article. All authors reviewed and approved the submitted article and have agreed to be accountable for its contents.

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CONFLICTS OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY

The data underlying this article cannot be shared publicly due to the privacy of individuals that participated in the app because they are sensible data of children. The data will be shared on reasonable request to the corresponding author.

REFERENCES

1. Sankilampi U, Saari A, Laine T, Miettinen PJ, Dunkel L. Use of electronic health records for automated screening of growth disorders in primary care. *JAMA* 2013; 310 (10):1071–2.
2. Wit JM, Kamp GA, Oostdijk W; on behalf of the Dutch Working Group on Triage and Diagnosis of Growth Disorders in Children. Towards a rational and efficient diagnostic approach in children referred for growth failure to the general paediatrician. *Hormone Res Paediatr* 2019; 91 (4): 223–40.
3. Cuda SE, Censani M. Pediatric obesity algorithm: a practical approach to obesity diagnosis and management. *Front Pediatr* 2018; 6: 431.
4. Dattilo AM, Birch L, Krebs NF, Lake A, Taveras EM, Saavedra JM. Need for early interventions in the prevention of pediatric overweight: a review and upcoming directions. *J Obes* 2012; 2012: 123023.
5. John M, Koledova E, Kumar KM, Chaudhari H. Challenges in the diagnosis and management of growth hormone deficiency in India. *Int J Endocrinol* 2016; 2016: 2967578.
6. Introduction. In: WHO Guideline Recommendations on Digital Interventions for Health System Strengthening. Vol. 1. 2019. https://www.ncbi. nlm.nih.gov/books/NBK541905/.
7. Fernandez-Luque L, Al Herbish A, Al Shammari R, *et al*. Digital health for supporting precision medicine in pediatric endocrine disorders: opportunities for improved patient care. *Front Pediatr* 2021; 9: 715705.
8. Tully L, Burls A, Sorensen J, El-Moslemany R, O'Malley G. Mobile health for pediatric weight management: systematic scoping review. *JMIR Mhealth Uhealth* 2020; 8 (6): e16214.

9. Labarta JI, Ranke MB, Maghnie M, *et al.* Important tools for use by pediatric endocrinologists in the assessment of short stature. *J Clin Res Pediatr Endocrinol* 2021; 13 (2): 124–35.
10. Dimitri P, Fernández-Luque L, Banerjee I, *et al.* An eHealth framework for managing pediatric growth disorders and growth hormone therapy. *J Med Internet Res* 2021; 23 (5): e27446.
11. Huang JW, Lin YY, Wu NY. The effectiveness of telemedicine on body mass index: a systematic review and meta-analysis. *J Telemed Telecare* 2019; 25 (7): 389–401.
12. Gomes AI, Pereira AI, Roberto MS, Boraska K, Barros L. Changing parental feeding practices through web-based interventions: a systematic review and meta-analysis. *PLoS One* 2021; 16 (4): e0250231.
13. Puspitasari P, Etikasari B, Puspitasari T, Kartika R, Perdanasari L, Kurniasari A. Android-based application for children's growth monitoring as acomplement for child development card. *J Teknokes* 15 (1): 44–50.
14. Fernández-Luque L, Labarta JI, Palmer E, Koledova E. Content analysis of apps for growth monitoring and growth hormone treatment: systematic search in the android app store. *JMIR Mhealth Uhealth* 2020; 8 (2): e16208.
15. Dunkel L, Fernández-Luque L, Loche S, Savage MO. Digital technologies to improve the precision of paediatric growth disorder diagnosis and management. *Growth Horm IGF Res* 2021; 59: 101408.
16. Koledova E, Le Masne Q, Spataru A, Bagha M, Dixon D. Digital health in the management of pediatric growth hormone therapy - 10 years of developments. *Stud Health Technol Inform* 2021; 281: 926–30.
17. Carrascosa Lezcano A, Fernández García JM, Fernández Ramos C, *et al.*; Grupo Colaborador Español. Spanish cross-sectional growth study 2008. Part II. Height, weight and body mass index values from birth to adulthood. *An Pediatr (Barc)* 2008; 68 (6): 552–69.
18. WHO. WHO Child Growth Standards. *Dev Med Child Neurol*. 2009; 51 (12): 1002.
19. CDC Growth Charts. 2000 Unites States. Advance Data No. 314. December 4. https://www.cdc.gov/nchs/data/ad/ad314.pdf.
20. Orden AB, Apezteguía MC. Weight and height centiles of Argentinian children and adolescents: a comparison with WHO and national growth references. *Ann Hum Biol* 2016; 43 (1): 9–17.
21. De Arriba Muñoz A, López Úbeda M, Rueda Caballero C, Labarta Aizpún JI, Ferrández Longás A. Normal values for body mass index and waist circumference in Spanish population from birth to 28 years old. *Nutr Hosp* 2016; 33 (4): 388.
22. Morlán Herrador L, de Arriba Muñoz A, Martínez Ruiz I, *et al.* Modelo estadístico para la prevención precoz de desarrollo de sobrepeso/obesidad en población infantil. *Bol Pediatr Arag Rioj Sor* 2017; 47 (3): 73–80.
23. Netchine I, van der Steen M, López-Bermejo A, Koledova E, Maghnie M. New horizons in short children born small for gestational age. *Front Pediatr* 2021; 9: 655931.
24. Serra-Majem L, Ribas L, Ngo J, *et al.* Food, youth and the Mediterranean diet in Spain. Development of KIDMED, Mediterranean diet Quality Index in children and adolescents. *Public Health Nutr* 2004; 7 (7): 931–5.
25. Serra-Majem L, Aranceta J, Ribas-Barba L, Sangil-Monroy M, Pérez-Rodrigo C. Crecimiento y desarrollo: dimensión alimentaria y nutricional. El cribado del riesgo nutricional en pediatría Validación del test rápido Krece Plus y resultados en la población Española. In: Crecimiento y Desarrollo Estudio Enkid. Vol. 4; 2003: 45–55.
26. Humphrey G, Dobson R, Parag V, *et al.* See How They Grow: Testing the feasibility of a mobile app to support parents' understanding of child growth charts. *PLoS One* 2021; 16 (2): e0246045.
27. Vaghefi I, Tulu B. The continued use of mobile health apps: insights from a longitudinal study. *JMIR Mhealth Uhealth* 2019; 7 (8): e12983.
28. Nyang'echi E, Osero J. Effects of mobile health technologies on uptake of routine growth monitoring among caregivers of children aged 9 to 18 months in Kenya. *J Prim Care Community Health* 2021; 12: 21501327211010995.
29. Hale I, Jackson E. Evaluating routine pediatric growth measurement as a screening tool for overweight and obese status. *Can Fam Physician* 2021; 67 (3): 161–5.
30. Black RE. Global prevalence of small for gestational age births. *Nestle Nutr Inst Workshop Ser* 2015; 81: 1–7.
31. Hocquette A, Durox M, Wood R, *et al.* International versus national growth charts for identifying small and large-for-gestational age newborns: A population-based study in 15 European countries. *Lancet Regional Health Europe* 2021; 8: 100167.
32. Savage MO, Backeljauw PF, Calzada R, *et al.* Early detection, referral, investigation, and diagnosis of children with growth disorders. *Horm Res Paediatr* 2016; 85 (5): 325–32.
33. Wronka I, Suliga E, Pawlińska-Chmara R. Evaluation of lifestyle of underweight, normal weight and overweight young women. *Coll Antropol* 2013; 37: 359–65.
34. Soliman AT, Itani M, Jour C, *et al.* Relation between changes in weight parameters and height parameters in prepubertal children: daily weight gain and BMIi changes in relation to linear growth during nutritional rehabilitation of underweight children. *Acta Biomed* 2019; 90 (8-s): 7–19.
35. Grote FK, Oostdijk W, De Muinck Keizer-Schrama SM, *et al.* Referral patterns of children with poor growth in primary health care. *BMC Public Health* 2007; 7: 77.
36. Thaventhiran T, Harding V, Hsu A, Dunkel L, Chapple P, Storr H. Development and testing of a novel 'GrowthMonitor' Smartphone App for growth monitoring and the detection of growth disorders. *EJEA* 2021; doi: 10.1530/endoabs.77.LB15.
37. Benavides C, Benítez-Andrades JA, Marqués-Sánchez P, Arias N. eHealth intervention to improve health habits in the adolescent population: mixed methods study. *JMIR Mhealth Uhealth* 2021; 9 (2): e20217.
38. World Health Organization. Media Center. Fact sheet Obesity and overweight. 2021. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight.
39. Di Cesare M, Sori c M, Bovet P, *et al.* The epidemiological burden of obesity in childhood: a worldwide epidemic requiring urgent action. *BMC Med* 2019; 17 (1): 212.
40. D'Innocenzo S, Biagi C, Lanari M. Obesity and the Mediterranean diet: a review of evidence of the role and sustainability of the Mediterranean diet. *Nutrients* 2019; 11 (6): 1306.
41. Bauman A, Rutter H, Baur L. Too little, too slowly: international perspectives on childhood obesity. *Public Health Res Pract* 2019; 29 (1): 2911901.
42. Domin A, Spruijt-Metz D, Theisen D, Ouzzahra Y, Vögele C. Smart-phone-based interventions for physical activity promotion: scoping review of the evidence over the last 10 years. *JMIR Mhealth Uhealth* 2021; 9 (7): e24308.
43. Giurgiu M, Timm I, Becker M, Schmidt S, Wunsch K, Nissen R. Quality evaluation of free-living validation studies for the assessment of 24-hour physical behavior in adults via wearables: systematic review. *JMIR Mhealth Uhealth* 2022; 10 (6): e36377.
44. Murphy J, Uttamlal T, Schmidtke KA, *et al.* Tracking physical activity using smart phone apps: assessing the ability of a current app and systematically collecting patient recommendations for future development. *BMC Med Inform Decis Mak* 2020; 20 (1): 17.
45. Evenson K, Furberg R. Moves app: A digital diary to track physical activity and location. *Br J Sports Med* 2017; 51 (15): 1169–70.
46. Kruizinga MD, Heide NV, Moll A, *et al.* Towards remote monitoring in pediatric care and clinical trials-Tolerability, repeatability and reference values of candidate digital endpoints derived from physical activity, heart rate and sleep in healthy children. *PLoS One* 2021; 16 (1): e0244877.