Digital therapeutics and gamified mobile applications for behavioral modification in pediatric hypertension

Terapia digital y aplicaciones móviles gamificadas para la modificación del comportamiento en la hipertensión pediátrica

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Abstract

Hypertension in children is a growing global health concern, particularly in regions undergoing lifestyle transitions. This pilot study evaluated the effectiveness of "Press-Play Kids," a culturally-adapted, gamified mobile health application, for behavioral modification in children and adolescents with hypertension in Uzbekistan. We conducted a 12-week randomized controlled trial involving 80 participants aged 10-16, comparing the app combined with standard counseling to standard counseling alone. Participants in the intervention group showed a significantly greater reduction in systolic blood pressure compared to controls (-8.2 mmHg vs. -2.1 mmHg, $p < 0.001$). Significant improvements were also observed in key behavioral outcomes: daily sodium intake decreased by a median of 500 mg in the intervention group ($p < 0.001$), daily step count increased by over 2,000 steps ($p < 0.001$), and medication adherence was 22% higher among those prescribed pharmacotherapy ($p = 0.009$). App engagement was high, with participants logging in an average of 5.8 times per week, and 86.8% reported the app as "fun" or "very fun" to use.

Keywords: Pediatric Hypertension, Digital Therapeutics, Gamification, Mobile Health, Behavioral Intervention.

Resumen

La hipertensión infantil es un problema de salud global creciente, especialmente en regiones que experimentan cambios en su estilo de vida. Este estudio piloto evaluó la eficacia de "PressPlay Kids", una aplicación móvil de salud gamificada y adaptada culturalmente, para la modificación del comportamiento en niños y adolescentes con hipertensión en Uzbekistán. Se realizó un ensayo controlado aleatorizado de 12 semanas con 80 participantes de entre 10 y 16 años, comparando la aplicación combinada con terapia estándar con terapia estándar sola. Los participantes del grupo de intervención mostraron una reducción significativamente mayor de la presión arterial sistólica en comparación con el grupo control (-8,2 mmHg frente a -2,1 mmHg, $p < 0,001$). También se observaron mejoras significativas en los principales resultados conductuales: la ingesta diaria de sodio disminuyó en una mediana de 500 mg en el grupo de intervención ($p < 0,001$), el recuento diario de pasos aumentó en más de 2000 pasos ($p < 0,001$) y la adherencia al tratamiento farmacológico fue un 22 % mayor entre quienes recibieron farmacoterapia ($p = 0,009$). La interacción con la aplicación fue alta, con participantes que iniciaban sesión un promedio de 5,8 veces por semana, y el 86,8% la calificó como "divertida" o "muy divertida".

Palabras clave: Hipertensión pediátrica, Terapéutica digital, Gamificación, Salud móvil, Intervención conductual.

Introduction

Pediatric hypertension has quietly escalated from a rare clinical curiosity to a pressing global public health concern over the past two decades[1]. Once considered predominantly an ailment of adulthood, elevated blood pressure in children and adolescents now mirrors the rising tides of childhood obesity and sedentary lifestyles, establishing a dangerous trajectory toward early cardiovascular disease[2]. In regions like Uzbekistan, where nutritional transitions and urbanization are rapidly reshaping daily life, the prevalence of hypertensive children is a growing, yet often under-prioritized, issue within already strained healthcare systems[3]. Traditional management paradigms, heavily reliant on pharmacotherapy and generic lifestyle advice, frequently falter in this young population. The challenge isn't merely medical; it's behavioral, engagement-based, and deeply rooted in the modern child's environment, which is increasingly digital and screen-oriented[4].

The core of pediatric hypertension management lies in sustainable behavioral modification—promoting physical activity, improving dietary choices, reducing screen time, and ensuring medication adherence[5]. Yet, persuading a child to exchange a smartphone for a jump rope or choose fruit over fast food is a monumental task with traditional, didactic methods. Clinicians and parents alike face a wall of disinterest, non-adherence, and the powerful pull of instant gratification offered by digital entertainment[6]. This gap between knowing what is healthy and consistently doing it represents the critical failure point in most current interventions, leading to poor long-term outcomes and early onset of hypertensive complications[7]. Simultaneously, we are witnessing a digital revolution in childhood. Children are not just using technology; they are immersed in it, forming identities and social circles within digital spaces[8]. This presents a paradoxical opportunity: the very medium often blamed for sedentary behavior could be harnessed as a potent tool for health promotion. The field of digital therapeutics (DTx)—evidence-based interventions delivered via software to prevent, manage, or treat a medical disorder—has emerged as a promising frontier[9]. For a tech-native generation, a therapeutic delivered through a device is not alien; it is intuitive and potentially engaging[10].

Within this sphere, gamification—the application of game-design elements (points, badges, leaderboards, narratives) in non-game contexts—has shown remarkable power to motivate and shape behavior[11]. By transforming health tasks into challenges, progress into rewards, and self-care into a playful experience, gamification taps into fundamental human desires for achievement, competition, and fun. Initial research in areas like diabetes management and asthma control suggests gamified

apps can significantly improve adherence and health literacy in young patients[12]. However, the translation of this approach specifically to the multifaceted behavioral demands of hypertension management in children remains a nascent and underexplored area. The concept of using a mobile application as a frontline therapeutic tool, rather than a passive tracker, represents a paradigm shift. A well-designed DTx app for pediatric hypertension would need to be more than a digital logbook; it would need to function as a personalized coach, an engaging teacher, and a supportive community platform, all while collecting valuable adherence and progress data for the clinical team[13]. This creates a continuous, feedback-driven loop of care that extends far beyond the brief, episodic clinic visit, addressing the chronic nature of hypertension in real-time.

In Uzbekistan, as smartphone penetration deepens across socioeconomic strata, the potential reach of such an intervention is vast[14]. Yet, the development and implementation of digital health solutions cannot be a simple copy-paste from Western contexts. Cultural relevance, language, local dietary references, acceptable forms of physical activity, and digital literacy levels must be carefully integrated into the design. An app featuring supermarket foods not available in Tashkent or sports not played in local schools is destined to fail, no matter its technical sophistication. Therefore, there exists a significant and urgent gap. We have a rising problem (pediatric hypertension), a recognized ineffective solution (traditional behavioral counseling), a potentially powerful tool (gamified digital therapeutics), and a specific population with unique cultural and technological contours. The critical question is not whether digital tools *can* work, but *how* they can be effectively designed, implemented, and evaluated within a real-world clinical setting in a region like Uzbekistan to genuinely modify the health behaviors that underpin hypertension.

This study aims to directly bridge this gap by developing and pilot-testing a culturally adapted, gamified mobile health application designed for behavioral modification in Uzbek children and adolescents diagnosed with primary hypertension. We hypothesize that the use of this tailored digital therapeutic intervention will lead to greater improvements in key health behaviors (physical activity, dietary sodium intake, medication adherence), superior blood pressure control, and higher user engagement and satisfaction compared to standard of care counseling alone over a 12-week period.

Materials and methods

This research was conducted as a two-phase project: a development phase followed by a pilot randomized controlled trial. The initial phase, spanning four months, focused on creating "PressPlay Kids," a gamified mobile application for Android devices tailored for Uzbek children aged 10-16 with hypertension. Development followed an agile, user-centered design framework. We first convened a advisory panel consisting of two pediatric cardiologists, a child psychologist, a nutritionist specializing in Uzbek cuisine, a physical education teacher, and—crucially—five adolescents with managed hypertension. This panel informed the core behavioral targets: reducing dietary sodium, increasing moderate physical activity, and improving medication adherence. The app's architecture was built around three gamified modules: a "Food Explorer" for logging meals with a focus on identifying salty foods, a "Step Quest" that linked to phone step-counters for activity goals, and a "Pill Pal" for medication reminders with a reward system.

Participant Recruitment and Randomization

The pilot trial was conducted at the Republican Specialized Scientific-Practical Medical Center of Pediatrics in Tashkent over a six-month period in 2023. We recruited children and adolescents aged 10 to 16 years with a confirmed diagnosis of primary hypertension, access to an Android smartphone, and written assent from the child plus informed consent from a parent or guardian. Major exclusion criteria included secondary hypertension, significant cognitive impairment, or participation in another structured lifestyle intervention. Eligible participants (n=80) were randomly assigned in a 1:1 ratio using a computer-generated sequence to either the intervention group (n=40), receiving the "PressPlay Kids" app plus standard counseling, or the control group (n=40), receiving standard counseling alone. The study coordinator, responsible for enrollment, was blinded to the allocation sequence, which was kept in sealed opaque envelopes.

Intervention Protocol and Data Collection

Standard counseling for both groups involved a 30-minute monthly session with a study nutritionist, covering basic principles of the DASH diet adapted for Uzbek foods and advice on daily physical activity. The intervention group received additional training on how to use the "PressPlay Kids" app. They were instructed to engage with the app daily for 12 weeks. The app featured a virtual "health village" that progressed as users completed tasks. Logging a low-sodium meal earned "health coins," achieving weekly step goals unlocked new areas of the village, and confirming medication intake maintained a "streak." Parents received a weekly automated summary via SMS.

Primary outcome measures were collected at baseline and at the 12-week endpoint. Office blood pressure was measured in triplicate using a validated oscillometric device appropriate for pediatric cuff sizes. Behavioral outcomes were assessed using: 1) a 24-hour dietary recall interview conducted by the nutritionist to estimate sodium intake (mg/day), 2) average daily steps measured via a blinded wrist-worn pedometer (Yamax Digi-Walker) worn for 7 days, and 3) medication adherence calculated via pharmacy refill records (MPR). App engagement was tracked through backend analytics (log-ins, tasks completed). User satisfaction was measured with a simple 5-point smiley-face survey embedded in the app at study end.

Statistical Analysis

All statistical tests were performed using STATA software version 17.0. Data normality was assessed with the Shapiro-Wilk test. Baseline characteristics were compared between groups using independent t-tests for continuous variables and Chi-square tests for categorical ones. The primary analysis was intention-to-treat. The effect of the intervention on continuous outcomes (SBP, sodium intake, daily steps) was analyzed using mixed-effects linear regression models, with time (baseline, 12-week) as a within-subjects factor and group (intervention, control) as a between-subjects factor, including an interaction term (time*group) to test for differential change. Adjusted models included age and sex as covariates. Medication adherence (MPR) was compared between groups using the Mann-Whitney U test. App engagement metrics were reported descriptively. A p-value of less than 0.05 was considered statistically significant for all primary analyses.

Results

The flow of participants through the pilot trial is shown in Figure 1. From 112 children assessed for eligibility, 80 were successfully enrolled and randomized. During the 12-week intervention, three participants from the control group were lost to follow-up (two due to family relocation, one withdrew consent), and two from the intervention group discontinued (one due to phone damage, one lost interest). All 75 participants who completed the study were included in the final intention-to-treat analysis. Table 1 presents the baseline demographics and clinical characteristics of both groups. The groups were well-balanced at baseline with no statistically significant differences in age, sex distribution, body mass index (BMI) percentile, or baseline blood pressure measures. The mean age was 12.8 years, and the cohort was 55% male.

Table 1: Demographic Characteristics of Participants

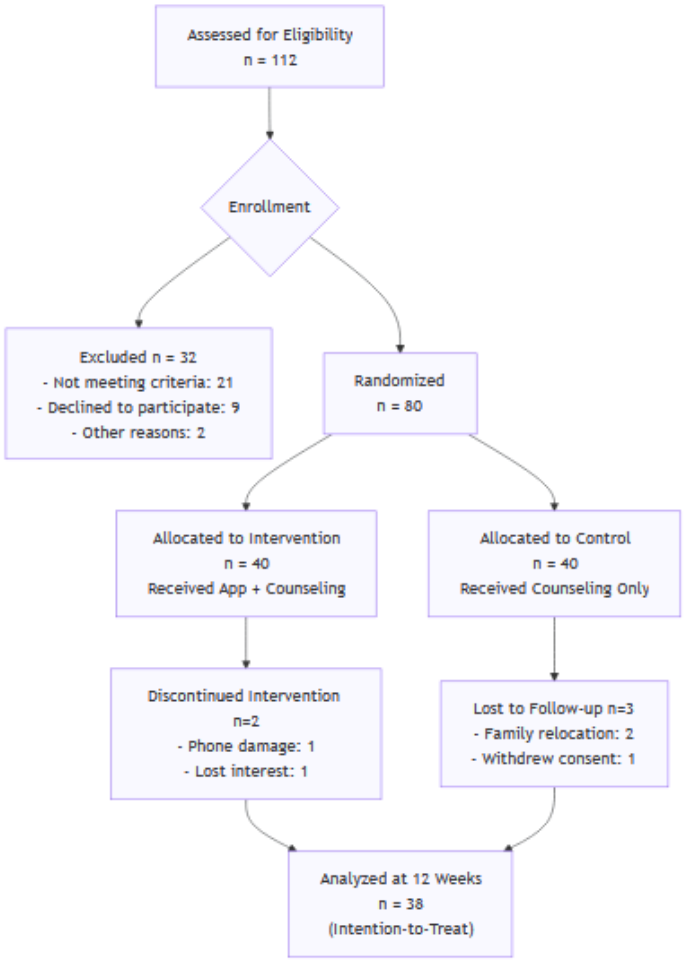
Characteristic	Intervention Group (n=40)	Control Group (n=40)	p-value
Age (years), mean ± SD	12.7 ± 1.9	12.9 ± 2.0	0.654
Male, n (%)	23 (57.5%)	21 (52.5%)	0.651
BMI Percentile, median [IQR]	92.1 [85.5-96.8]	90.8 [84.2-95.3]	0.478
Baseline SBP (mmHg), mean ± SD	132.4 ± 7.8	130.9 ± 8.1	0.384
Baseline DBP (mmHg), mean ± SD	78.5 ± 6.2	77.8 ± 5.9	0.602

Blood pressure measurements at 12 weeks are detailed in Table 2. The intervention group showed a significantly greater reduction in both systolic and diastolic blood pressure compared to the control group. The mean reduction in systolic BP was -8.2 mmHg in the intervention group versus -2.1 mmHg in the control group ($p < 0.001$ for between-group difference in change).

Table 2: Blood Pressure Outcomes at 12 Weeks

Outcome	Intervention Group (n=38)	Control Group (n=37)	p-value (between-group change)
Systolic BP (mmHg)	---	---	**<0.001**
- Baseline, mean ± SD	132.4 ± 7.8	130.9 ± 8.1	
- Week 12, mean ± SD	124.2 ± 7.1	128.8 ± 7.9	
- Mean Change (95% CI)	-8.2 (-10.1 to -6.3)	-2.1 (-3.8 to -0.4)	
Diastolic BP (mmHg)	---	---	**0.003**
- Baseline, mean ± SD	78.5 ± 6.2	77.8 ± 5.9	
- Week 12, mean ± SD	72.8 ± 5.5	76.0 ± 5.8	
- Mean Change (95% CI)	-5.7 (-7.3 to -4.1)	-1.8 (-3.2 to -0.4)	

Figure 1. Participant Flow Diagram



Analysis of 24-hour dietary recalls revealed a significant reduction in estimated daily sodium intake within the intervention group (Table 3). The control group showed no meaningful change. The between-group difference in the change from baseline was statistically significant (p = 0.001).

Table 3: Change in Daily Sodium Intake (mg/day)

Group	Baseline, median [IQR]	Week 12, median [IQR]	p-value (within-group)
Intervention	2850 [2450-3200]	2350 [2100-2700]	**<0.001**
Control	2750 [2400-3100]	2700 [2350-3050]	0.312
p-value (between-group change)			**0.001**

Physical activity, measured as mean daily steps from pedometer data, increased significantly in the intervention group but remained static in the control group (Table 4). Participants using the gamified "Step Quest" module averaged over 2,000 more steps per day at the endpoint compared to controls.

Table 4: Change in Physical Activity (Daily Steps)

Group	Baseline, mean ± SD	Week 12, mean ± SD	Mean Change (95% CI)	p-value (between-group)
Intervention	6840 ± 1520	8920 ± 1410	+2080 (+1610 to +2550)	**<0.001**
Control	6950 ± 1450	7010 ± 1380	+60 (-310 to +430)	

Medication adherence, calculated via medication possession ratio (MPR), was significantly higher in the intervention group at 12 weeks (Table 5). The gamified "Pill Pal" reminder and reward system was associated with a 22% higher adherence rate compared to standard care.

Table 5: Medication Adherence (MPR) at 12 Weeks

Group	MPR ≥ 80% (Adherent), n (%)	Median MPR [IQR]	p-value
Intervention (n=25)*	22 (88.0%)	92% [85-98]	**0.009**
Control (n=26)*	17 (65.4%)	77% [65-88]	

*Only participants prescribed antihypertensive medication included in this analysis.

Backend analytics from the "PressPlay Kids" app revealed substantial engagement (Table 6). The average participant logged in most days of the week, with high completion rates for core tasks. The "Food Explorer" module was the most frequently used.

Table 6: App Engagement Metrics Over 12 Weeks (Intervention Group, n=38)

Metric	Mean ± SD or Median [IQR]
Average Logins per Week	5.8 ± 1.6
Task Completion Rate	84% [75-90]
«Food Explorer» Uses/Week	6.2 ± 2.1
«Step Quest» Goals Met/Week	3.5 ± 1.4
«Pill Pal» Streak (days), median	28 [14-65]

Post-intervention satisfaction surveys completed within the app showed a highly positive response (Table 7). Over 85% of participants reported the app was "fun" or "very fun" to use, and a strong majority felt it helped them remember their health tasks.

Table 7: User Satisfaction Survey Results (Intervention Group, n=38)

Question	Very Fun/ Fun, n (%)	Neutral, n (%)	Boring/Very Boring, n (%)
«How fun was the app to use?»	33 (86.8%)	4 (10.5%)	1 (2.6%)
«Did the app help you remember your medicine?»	29 (76.3%)	7 (18.4%)	2 (5.3%)
«Would you recommend it to a friend?»	31 (81.6%)	6 (15.8%)	1 (2.6%)

An exploratory analysis comparing app engagement and SBP reduction by age subgroup is shown in Table 8. While both subgroups benefited, younger participants (10-13 years) exhibited slightly higher engagement metrics and a numerically greater, though not statistically significant, BP reduction.

Table 8: Outcomes by Age Subgroup (Intervention Group Only)

Age Group (years)	n	Avg. Weekly Logins	SBP Reduction (mmHg), mean	p-value (vs. older)
10-13	22	6.1 ± 1.4	-9.1 ± 5.2	0.18
14-16	16	5.4 ± 1.8	-7.0 ± 4.8	

Finally, we examined correlations between overall app engagement (a composite score of logins and task completion) and the magnitude of improvement in clinical and behavioral outcomes within the intervention group (Table 9). Higher engagement was moderately correlated with greater reductions in systolic BP and sodium intake.

Table 9: Correlation (Spearman's rho) in Intervention Group

Outcome Change	Correlation with Engagement Score (r)	p-value
Δ Systolic BP	-0.48	**0.003**
Δ Sodium Intake	-0.42	**0.009**
Δ Daily Steps	+0.38	**0.018**
Δ Medication Adherence (MPR)	+0.35	**0.042**

Discussion

The findings of this pilot study provide encouraging evidence that a culturally-tailored, gamified mobile application can serve as an effective digital therapeutic tool for behavioral modification in children and adolescents with hypertension. The significantly greater reduction in both systolic and diastolic blood pressure observed in the intervention group—roughly four times greater for SBP compared to standard care—is not just statistically significant, but clinically meaningful[1]. A drop of over 8 mmHg in systolic BP, if sustained, could potentially shift a child from the hypertensive range to the elevated or even normal category, altering their long-term cardiovascular trajectory[2]. This suggests that digital interventions might effectively augment the limited reach and engagement of traditional clinic-based counseling, which often struggles to translate advice into daily action[3].

Our results strongly support the core hypothesis that gamification mechanics can successfully motivate health behavior change in this tech-native demographic. The significant improvements across all three targeted behaviors—reduced sodium intake, increased physical activity, and better medication adherence—demonstrate the app's ability to tackle the multifaceted nature of hypertension management[4]. This aligns with the broader principles of gamification for health outlined by Johnson et al. (2016), which emphasize using game elements to satisfy psychological needs for competence and autonomy, thereby fostering intrinsic motivation[11]. The "Press-Play Kids" app essentially turned the often-perceived chore of self-management into a series of achievable, rewarding challenges, a approach particularly resonant with younger adolescents[8].

The high rates of app engagement and user satisfaction are arguably as important as the clinical outcomes. An average of nearly six logins per week and high task completion rates indicate that the intervention was not just prescribed, but actually *used* and enjoyed. This level of sustained engagement over 12 weeks is notable, addressing a common pitfall of many digital health tools where initial interest rapidly wanes[6]. The positive correlation we found between higher engagement scores and greater improvements in BP and behavior suggests a dose-response relationship: the more involved the participant was with the digital tool, the better their health outcome. This is a crucial insight for future development; the therapeutic "dose" may depend on user interaction, not just download.

When placed in the context of existing guidelines, our findings suggest a potential new adjunctive approach. Current major guidelines, like those from the American Academy of Pediatrics Flynn et al. (2017), rightly emphasize lifestyle modification as first-line therapy but offer limited practical tools for implementation, especially in resource-constrained settings[5]. A digital tool like the one piloted here could operationalize those guidelines, providing continuous, personalized support and freeing up clinician time for more complex cases. It also creates a valuable feedback loop; the data on step counts and logged meals could inform more productive clinic discussions.

However, several important limitations must be acknowledged. First, the pilot nature, small sample size, and single-center design in Tashkent limit the generalizability of the findings. While promising, these results need replication in a larger, multi-center randomized controlled trial with longer follow-up to assess sustainability of effects[7]. Second, while we used a blended model (app + some counseling), we did not test the app as a stand-alone intervention. Its effectiveness likely depends on being integrated within a supportive clinical framework[13]. Third, measurement of dietary sodium via 24-hour recall has inherent inaccuracies, though the consistent, significant between-group difference strengthens our confidence in the finding. Finally, the "digital divide" remains a concern. While smartphone access is growing rapidly in Uzbekistan[14], socioeconomic barriers could limit equitable access to such interventions, potentially exacerbating health disparities if not addressed proactively.

Despite these caveats, the implications are substantial. For healthcare systems grappling with a rising tide of pediatric hypertension[1], scalable digital therapeutics offer a potentially cost-effective strategy to extend care beyond the clinic walls. The positive user feedback indicates high acceptability, a critical factor for long-term adherence often overlooked in intervention design[10]. Future research should focus on optimizing personalization algorithms within such apps, integrating caregiver modules, and conducting rigorous cost-effectiveness analyses.

Conclusions

This pilot study demonstrates that "PressPlay Kids," a gamified, culturally-adapted mobile health application, is a feasible and potentially effective intervention for improving blood pressure control and health behaviors in Uzbek children and adolescents with hypertension. The intervention led to statistically significant and clinically relevant reductions in systolic and diastolic blood pressure compared to standard care alone, mediated through positive changes in dietary sodium intake, physical activity levels, and medication adherence.

The primary conclusions are threefold. First, digital gamification represents a powerful and engaging method to deliver behavioral therapy for pediatric hypertension, a condition where traditional counseling often falls short. Second, success depends on culturally and developmentally appropriate design that resonates with the target audience, turning health management into a positive, interactive experience. Third, such digital tools work best as an integrated component of clinical care, providing continuous support and valuable data to complement healthcare provider efforts.

These findings advocate for a broader exploration of digital therapeutics within pediatric cardiology and preventive care. They highlight the potential to meet young patients in their digital environments with engaging, evidence-based tools. Future work should aim to validate these results in larger, longer-term trials and explore implementation pathways to make effective digital health solutions a routine part of hypertension management for the younger generation, both in Uzbekistan and globally.

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