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Persistent effect of salt reduction in schoolchildren and their families: 1-year follow-up after an application-based cluster randomized controlled trial

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Abstract

Background A 12-month cluster randomized controlled trial (RCT) demonstrated the effectiveness of an application-based education program in reducing the salt intake and systolic blood pressure (SBP) of schoolchildren's adult family members. This study aimed to assess whether the effect at 12 months persisted at 24 months.

Methods Fifty-four schools were randomly assigned to either the intervention or control group. All participants (594 children in grade 3 and 1188 of their adult family members) who completed the baseline survey were contacted again 12 months after the trial. The primary outcome was the difference in salt intake change between the intervention and control groups at 24 months versus baseline and 12 months, measured by the mean two consecutive 24-h urinary sodium excretions. The secondary outcome was the difference in the change of blood pressure and salt-related Knowledge, Attitude, Practice (KAP) score.

Results The difference in salt intake change in adults between the intervention and control groups after adjusting for confounding factors was −0.38 g/day at 24 months versus baseline (95% CI −0.81 to 0.05, $p=0.09$), following the −0.83 g/day (95% CI −1.25 to −0.41, $p<0.001$) at 12 months. The adjusted difference in SBP change was −2.19 mm Hg (95% CI −3.63 to −0.76, $p=0.003$) at 24 months versus baseline, following the −1.80 mm Hg (95% CI −3.19 to −0.40, $p=0.01$) at 12 months. The intervention group had a higher KAP score than the control group both at 12 months and at 24 months versus baseline. No significant changes were found in children.

Conclusions The effect of the education program on adults' salt intake faded, but the SBP lowering effect and the improvement of KAP score remained 12 months after the completion of the RCT. Continuous efforts are needed to maintain the salt reduction effects in real-world settings.

Trial registration ChiCTR1800017553. Registered on August 3, 2018.

Keywords Salt reduction, Blood pressure, Follow-up, Persistent effect

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Background

Excess consumption of salt is a well-established cause of raised blood pressure and increased risk of cardiovascular disease [1, 2]. This unhealthy dietary factor is associated with over 1.8 million deaths each year worldwide [3]. Reducing salt intake is regarded as one of the best cost-effective ways to improve health and save lives [4]. However, the global progress on salt reduction is barely satisfactory, partly due to the difficulty of changing people's salt intake behavior in particular for those countries where discretionary salt is widely used [5]. Innovative approaches are encouraged to facilitate the global action. School-based intervention has shown to be a promising strategy to improve health outcomes both in children and their families, as the children and the parents are mutually affected in terms of health behavior [6, 7]. Moreover, the digital health especially the mobile health (mHealth) interventions demonstrate great potential in supporting behavior change alongside the unprecedented coverage of intelligent mobile phones [8, 9]. A recent review indicated that technology-supported behavior change interventions are effective in reducing salt intake and blood pressure [10].

By combining mHealth with school-based interventions, one of our previous cluster randomized controlled trials (RCT) developed an innovative application (app) based education program to reduce salt intake in schoolchildren and their families in China (AppSalt) [11]. The process evaluation of AppSalt found a 97% retention rate of the AppSalt program and an 80% completion rate of the whole app-based salt reduction courses, indicating the feasibility and acceptability of the interventions [12]. The results of AppSalt showed that the app-based education program conducted through schoolchildren is effective in reducing the salt intake of their adult family members by 0.82 g/day after a 12-month intervention, along with a 1.64-mm Hg drop of systolic blood pressure (SBP) [13]. However, the long-term effect after the RCT is still unknown.

Among the few reports on the long-term effects of salt reduction, three trials that examined the impact of salt reduction on blood pressure over a period of more than 6 months indicated a resurgence in both salt intake and blood pressure levels over time [14–16]. In contrast, three population-based studies from the UK, Finland, and Iran, which spanned several years, suggested that the changes in salt intake and blood pressure were not as consistent as those in trials, with population-wide salt reduction leading to a much greater fall in blood pressure than that observed in intervention trials [17–19]. No relevant research was identified that addresses the enduring effects subsequent to the conclusion of the trial. This study aimed to evaluate whether the app-based intervention yielded sustained effects on the reduction of salt intake among children and their families following the termination of the intervention trial.

Methods

Study design and participants

This study (AppSalt) was designed upon a successful RCT (School-EduSalt), which encouraged children to deliver the salt-related knowledge and skills learned from schools to their families [20]. Guided by the same behavior change theories including health belief model and social determinants of health, AppSalt integrated the traditional health education course and family salt intake monitoring task into a mobile app that could be installed in parents' phones to facilitate the engagement of families. The details of the study design and interventions have been described in previous publications [11, 13, 21]. In summary, the study is a parallel, cluster randomized controlled trial (RCT) carried out in 54 primary schools from three cities of China, with schools randomly assigned to either intervention or control group (1:1). Randomization of schools (clusters) took place after baseline data collection, through a computer-generated, central randomization system, stratified by the location of schools (southern, central, or northern China). The participants and researchers who undertook recruitment and the baseline data collection were blinded of the allocation until the intervention stage.

It was estimated that a sample size of 594 children from 54 schools would provide 80% power ($\alpha = 0.05$) to detect a mean difference of ≥ 26 mmol/day sodium (1.5 g/day of salt) between the two groups, assuming a standard deviation of 85 mmol/day sodium and an intraclass correlation coefficient of 0.05 and allowing for a 15% dropout rate. A total of 1188 adults were recruited by selecting two adults from each family [13]. As such, we randomly selected 11 children and 22 adult family members from one class in grade 3 (age 8–9 years) of each school for outcome assessments. The inclusion criteria included: (1) Children and the adult family members ate homemade meals at least four times per week. (2) One adult family member had a mobile device with internet access. (3) The two adult family members were selected in the order of grandparents, parents, and others (uncles and aunts) if more than two adults in a family were eligible. (4) Participants had been residents in the local communities for more than 6 months. The exclusion for outcome assessments were individuals who could not or refused to collect 24-h urine samples.

Multifaceted interventions lasting 12 months (2 school terms) were carried out in all the grade 3 classes of the 27 schools in the intervention group. The main components of the intervention were salt reduction education and monitoring via the app-based platform. Children were asked to complete 9 lessons on salt reduction education and 12 health education lessons together with their adult family members via an app (AppSalt) installed in parents' mobile phones. Each lesson was about 10 min followed by a quiz of 10 questions and a practical session (e.g., preparing foods with less salt at home or selecting lower salt products when shopping). Teachers would remind the completion of the online course and organize offline activities in classes including art and knowledge competitions and health education class on salt reduction. Supportive environments were encouraged to be created on campuses such as putting up salt awareness posters in canteens and playing salt and health broadcast series during break times.

Procedures

A total of 594 children and 1188 adult family members were randomly selected for baseline evaluation in September 2018. The trial endline survey (the 12-month follow-up) was carried out in September 2019. The post-trial evaluation (the 24-month follow-up) was originally considered and was introduced in the protocol of the Action on Salt China program, which included AppSalt and other three RCTs targeting salt reduction in schoolchildren, home cook, communities, and restaurants, respectively [21]. All the health education materials used for intervention are publicly available after the trial, but the schools were not obliged to conduct the interventions anymore. The 24-month follow-up evaluation was conducted between September and December 2020, i.e., 12 months after the completion of the trial and at 24 months of the baseline. All participants who completed the baseline survey were contacted again at 24 months, regardless of their follow-up status at 12 months.

Outcomes

The primary outcome was the difference in salt intake change between the intervention and control groups for children and for adults at 24 months versus baseline and 12 months. The secondary outcome was the difference in SBP and diastolic blood pressure (DBP) change in adults and the change of salt-related Knowledge, Attitude, Practice (KAP) score in children and in adults at 24 months versus baseline and 12 months.

The same protocol as the trial was followed to collect the outcome data. Two consecutive 24-h urines were collected under a standardized procedure with the support of the electronic data collection system. Urine volume was measured by urine weight. Urinary sodium, potassium, and creatinine levels were tested in the central laboratory of KingMed Diagnostics Center, using an ion-selective electrode method for the measurement of sodium and potassium, and an enzymatic method for creatinine. Salt intake (g/day) was estimated by urinary sodium excretion (mmol/24 h) by dividing 1000 and multiplying 58.5 g/mol. Trained researchers measured blood pressure, body weight, and height using the same measurement tools and interviewed the same KAP questions as the trial following the standardized protocol.

Statistical analysis

According to previous studies, the urine samples meeting the following criteria had a great possibility of collecting incomplete 24-h urines: (1) the urine collection time was less than 20 h or more than 28 h; or (2) the 24-h urine volume was < 500 mL in adults or < 300 mL in children; or (3) the 24-h urinary creatinine was < 4.0 mmol in women or < 6.0 mmol in men, or lower than the 5th centile (< 2.33 mmol for girls and < 3.11 mmol for boys) [13, 20]. We excluded these possibly incomplete urine samples in the main analysis. For the included urine samples, we calculated the 24-h urine volume (mL) as urine volume (mL) divided by duration of urine collection (hours) and multiplied by 24 h. The 24-h urinary sodium, potassium, and creatinine excretions were calculated by multiplying their urinary concentrations with 24-h urine volume. For KAP score, we adopted the definition for adults and children in reference to a previous analysis using the same questionnaires that were developed by the research team and were validated through the pilot study (Additional file 1: Table S1, S2) [22]. The score range is 0 ~ 10 for adults and 0 ~ 6 for children. A higher KAP score indicates better awareness and practice related to salt.

Schools and participants were analyzed according to their randomly assigned groups following the intention-to-treat principle. Mixed linear models were performed to test the effects of the intervention on outcomes. The models included random intercept and fixed effect. The hierarchical structure was reflected in random effect with three visits (baseline, 12 months, and 24 months) for each participant, at most 2 participants for each family only in the model for adults, and up to 11 families for each school. The fixed effect variables included groups, visits, and covariates. The potential confounding variables listed as covariates included age, sex, body mass index (BMI; body weight in children instead), outdoor temperature, and the highest education level of the adult participants in the family. In the models for blood pressure outcomes, the covariates also included physical activity and alcohol consumption for adults. Participants were considered physically active if they reported engaging in moderate physical activity at least 3 times a week and at least 30 min per time. The difference between the two groups at 24 months compared to baseline and 12 months was estimated through designated LSMESTIMATE command in the models.

We performed subgroup analyses to separately evaluate salt intake and systolic blood pressure across subgroups of various factors. For both children and adults, we looked at differences by sex (Male and female), study site (Shijiazhuang, Yueyang, and Luzhou), and education levels (the highest education in the family: secondary education or lower, high school, and university or college). For adults exclusively, we also considered differences across the blood pressure status (normotensive and hypertensive) and adults' relationship with children (parents, grandparents, and other relatives).

We conducted three sensitivity analyses to examine the robustness of the results: (1) multiple imputation for salt intake and systolic blood pressure. Missing data were imputed using a sequential multiple imputation approach assuming missing at random. The covariates used for imputation were the same as those mentioned above. The imputation was done for each group separately and applied to 100 copies of the dataset. (2) included all participants with possibly incomplete 24-h urine collections. (3) included only participants who completed all the three visits.

The statistical analyses were performed using SAS Enterprise Guide 8.3 (SAS Institute). All analyses were two-sided and $P<0.05$ was considered significant.

Results

A total of 592 children and 1184 adults completed baseline assessment in 2018. The mean age at baseline were 8.6 years for children in both groups, and 46.8 (SD 13.1) years and 44.9 (SD 12.6) years for adults in intervention and control group respectively. At 24 months, 542 children and 976 adults were followed up, accounting for 91.6% and 82.4% of the participants, respectively. The follow-up rates in the intervention group and control group were 92.3% (274/297) and 90.8% (268/295) in children and 81.1% (482/594) and 83.7% (494/590) in adults, respectively (Fig. 1). The baseline characteristics of participants are shown in Table 1. In adults, the participants who lost to follow-up had a higher proportion of men compared to those who were followed up.

The line graph of unadjusted mean salt intake across the three visits showed that the average increased or plateaued from 12 months visit to 24 months visit in adults and children in both the control group and the intervention group, irrespective of the trend from baseline to 12 months visit (Fig. 2). The mean salt intake at baseline, 12 months, and 24 months can be also found in Additional file 1: Table S3. The mean difference in salt intake change in adults between the intervention and control groups after adjusting for confounding factors is −0.38 g/day at 24 months versus baseline (95% CI −0.81 to 0.05, $p=0.09$), and 0.45 g/day at 24 months versus 12 months (95% CI 0.01 to 0.85, $p=0.05$), following 0.83 g salt reduction effect of the 12-month intervention (Table 2). The sample size for analysis can be found in Table S4.

The mean SBP in adults at 24 months was 118.4 (SD 16.4) mm Hg and 120.7 (SD 16.6) mm Hg in the intervention group and control group, respectively, despite that the SBP increased from 12 to 24 months in both groups (Fig. 2 and Additional file 1: Table S3). After the 1.80 mm Hg decrease of SBP was observed at the end of the intervention, the mean difference in SBP change after adjusting for confounding factors is −2.19 mm Hg (95% CI −3.63 to −0.76, $p=0.003$) at 24 months versus baseline and −0.40 mm Hg (95% CI −1.86 to 1.07, $p=0.60$) at 24 months versus 12 months. No significant difference was found in the change of salt intake and SBP in children at 24 months versus baseline or 12 months in the final model adjusting for confounding factors, nor was the urinary potassium, sodium-to-potassium ratio, and DBP in adults and children (Table 2).

The KAP score increased with visits both in children and in adults except that the children in the intervention group scored the same at the two follow-up visits (Additional file 1: Table S3). After adjusting for confounding factors, the intervention group showed a significantly higher KAP score than the control group both at 12 months and at 24 months versus baseline though the difference decreased from 0.81 (95% CI 0.62 to 1.00, $p<0.001$) to 0.62 (95% CI 0.43 to 0.82, $p<0.001$) in adults and from 1.25 (95% CI 1.04 to 1.46, $p<0.001$) to 0.80 (95% CI 0.59 to 1.01, $p<0.001$) in children (Table 2).

Sensitivity analyses for salt intake and SBP in adults showed similar effects as those in the main analyses (Additional file 1: Table S4–S6). The subgroup analyses of salt intake and SBP at 24 months versus baseline were mostly not significant, except that in adults the effect of salt intake was significantly different across the subgroups of education level (p for interaction = 0.04), blood pressure status (p for interaction = 0.002) and adult's relationship with children (p for interaction = 0.01), among which only the mean effect for children's parents showed statistical significance (−1.18, 95% CI −1.96 to −0.39) (Additional file 1: Table S7–S8, Fig. S1).

Discussion

This study explores the persistent effect of salt reduction in schoolchildren and their families by following up the participants 1 year after the completion of a cluster RCT which implemented an app-based salt reduction package to families via primary schools over 12 months. The results showed that in adults, the salt reduction achieved over the intervention stage attenuated from 0.83 g/day

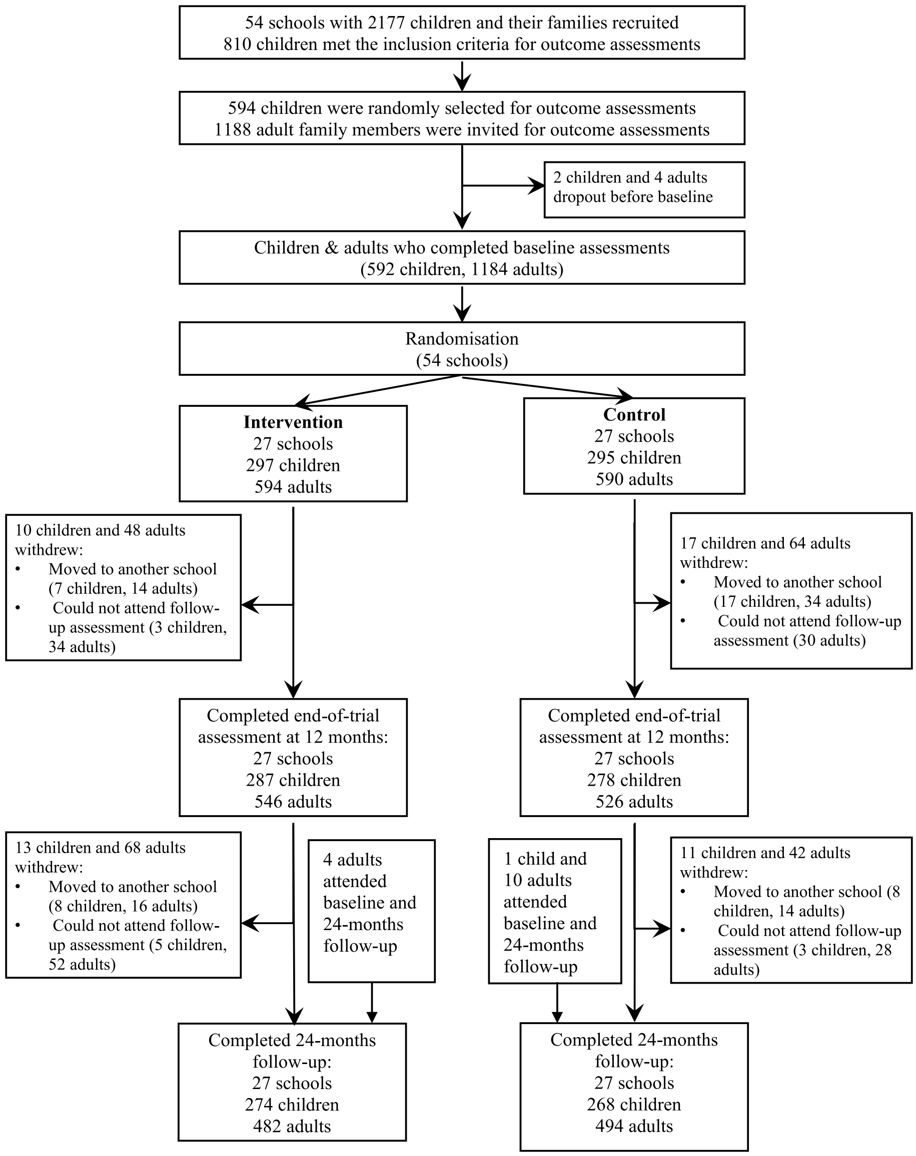

Fig. 1 Flowchart of participants

to 0.38 g/day, while the SBP maintained about 2 mm Hg reduction effect at the 24-month follow-up. In children, there were no significant effects in reducing salt intake and blood pressure across the 24 months, whereas the improvement of KAP score persisted both in children and in adults with a mitigated effect size.

The relapse of the intervention effect on salt intake in adults was due to the rebound of salt intake from 8.9 g/day to 9.4 g/day in the intervention group while the mean salt intake in the control group stabilized at 9.8 g/day after the trial, in the context that the two groups both consumed 10 g/day of salt at baseline. These findings are not surprising, given the challenge that participants need to maintain a lower salt intake without further support from the research team. The application-based salt reduction interventions that were implemented during the RCT, including health education courses, target setting and self-monitoring, and communications with children and school teachers, would motivate adults to reduce their salt intake [13, 23]. Once the motivation stopped, it would be hard for the participants to adhere to the new behavior, especially when the food environment is conducive to a high salt diet [5]. To a certain extent, the steady salt intake in the control group also indicates the standstill of the food environment.

Table 1 Baseline characteristics of participants with 24-month follow-up status

Characteristics	Intervention				Control			
	Follow-up	**Drop-out**	***p* value**	**Total**	**Follow-up**	**Drop-out**	***p* value**	**Total**
Cluster level	*n* = 27	*n* = 0		*n* = 27	*n* = 27	*n* = 0		*n* = 27
No. (%) of schools by location								
Shijiazhuang	9 (33.3)	0 (0.0)		9 (33.3)	9 (33.3)	0 (0.0)		9 (33.3)
Yueyang	9 (33.3)	0 (0.0)		9 (33.3)	9 (33.3)	0 (0.0)		9 (33.3)
Luzhou	9 (33.3)	0 (0.0)		9 (33.3)	9 (33.3)	0 (0.0)		9 (33.3)
No. (%) of families	274 (100.0)	23 (100.0)		297 (100.0)	268 (100.0)	27 (100.0)		295 (100.0)
Outdoor temperature (°C), mean (SD)	18.8 (5.0)	19.3 (5.3)	0.63	18.8 (5.0)	19.8 (4.8)	17.4 (4.2)	0.02	19.6 (4.8)
Children level	*n* = 274	*n* = 23		*n* = 297	*n* = 268	*n* = 27		*n* = 295
No. (%) of boys	140 (51.1)	12 (52.2)	0.92	152 (51.2)	141 (52.6)	15 (55.6)	0.77	156 (52.9)
Age (year), mean (SD)	8.6 (0.3)	8.7 (0.3)	0.44	8.6 (0.3)	8.6 (0.5)	8.8 (0.6)	0.02	8.6 (0.5)
Weight (kg), mean (SD)	30.4 (7.4)	31.8 (8.4)	0.38	30.5 (7.5)	29.6 (6.9)	31.9 (6.6)	0.11	29.8 (6.9)
BMI (kg/m^2), mean (SD)	17.3 (3.1)	18.1 (3.4)	0.24	17.4 (3.1)	17.0 (2.8)	18.1 (3.3)	0.07	17.1 (2.9)
Physical activity, No. (%)			0.67				0.38	
No	132 (48.2)	10 (43.5)		142 (47.8)	135 (50.4)	16 (59.3)		151 (51.2)
Yes	142 (51.8)	13 (56.5)		155 (52.2)	133 (49.6)	11 (40.7)		144 (48.8)
Highest education in the family, No. (%)			0.79				0.08	
Primary education	25 (9.1)	1 (4.3)		26 (8.8)	22 (8.2)	3 (11.1)		25 (8.5)
Secondary education	67 (24.5)	5 (21.7)		72 (24.2)	46 (17.2)	9 (33.3)		55 (18.6)
High school education	86 (31.4)	7 (30.4)		93 (31.3)	96 (35.8)	4 (14.8)		100 (33.9)
College education	96 (35.0)	10 (43.5)		106 (35.7)	104 (38.8)	11 (40.7)		115 (39.0)
Adult level	*n* = 482	*n* = 112		*n* = 594	*n* = 494	*n* = 96		*n* = 590
No. (%) of men	208 (43.2)	64 (57.1)	0.007	272 (45.8)	221 (44.7)	58 (60.4)	0.005	279 (47.3)
Relationship with children, No. (%)			0.05				0.04	
Parents	137 (28.4)	43 (38.4)		180 (30.3)	152 (30.8)	42 (43.8)		194 (32.9)
Grandparents	214 (44.4)	37 (33.0)		251 (42.3)	226 (45.7)	34 (35.4)		260 (44.1)
Other relatives	131 (27.2)	32 (28.6)		163 (27.4)	116 (23.5)	20 (20.8)		136 (23.1)
Age (year), mean (SD)	47.0 (12.9)	45.9 (14.0)	0.42	46.8 (13.1)	45.1 (12.8)	43.8 (11.7)	0.33	44.9 (12.6)
Weight (kg), mean (SD)	64.9 (12.7)	66.9 (12.3)	0.14	65.3 (12.6)	65.6 (12.7)	65.2 (12.8)	0.76	65.5 (12.7)
BMI (kg/m^2), mean (SD)	25.0 (3.8)	25.3 (3.6)	0.51	25.1 (3.8)	25.1 (3.6)	24.7 (3.7)	0.25	25.1 (3.6)
Physical activity, No. (%)			0.71				0.99	
No	327 (67.8)	78 (69.6)		405 (68.2)	334 (67.6)	65 (67.7)		399 (67.6)
Yes	155 (32.2)	34 (30.4)		189 (31.8)	160 (32.4)	31 (32.3)		191 (32.4)
Highest education, No. (%)			0.05				0.07	
Primary education	88 (18.3)	29 (25.9)		117 (19.7)	89 (18.0)	17 (17.7)		106 (18.0)
Secondary education	125 (25.9)	36 (32.1)		161 (27.1)	110 (22.3)	30 (31.3)		140 (23.7)
High school education	141 (29.3)	22 (19.6)		163 (27.4)	151 (30.6)	18 (18.8)		169 (28.6)
College education	128 (26.6)	25 (22.3)		153 (25.8)	144 (29.1)	31 (32.3)		175 (29.7)
Alcohol drinkers, No. (%)			0.24				0.84	
Non-drinkers	275 (57.1)	54 (48.2)		329 (55.4)	283 (57.3)	52 (54.2)		335 (56.8)
Occasional drinkers	172 (35.7)	48 (42.9)		220 (37.0)	170 (34.4)	35 (36.5)		205 (34.7)
Regular drinkers	35 (7.3)	10 (8.9)		45 (7.6)	41 (8.3)	9 (9.4)		50 (8.5)
Self-reported hypertension, No. (%)	58 (12.0)	13 (11.6)	0.01	71 (12.0)	55 (11.1)	14 (14.6)	0.61	69 (11.7)

Note: Chisq-test for categorical variables and *t*-test for continuous variables

Previous studies have also shown that it is extremely difficult for individuals to maintain a lower salt intake for a long period of time without change of food environment. For example, the Trials of Hypertension Prevention Research showed that net changes in body weight, sodium excretion, and BP all gradually

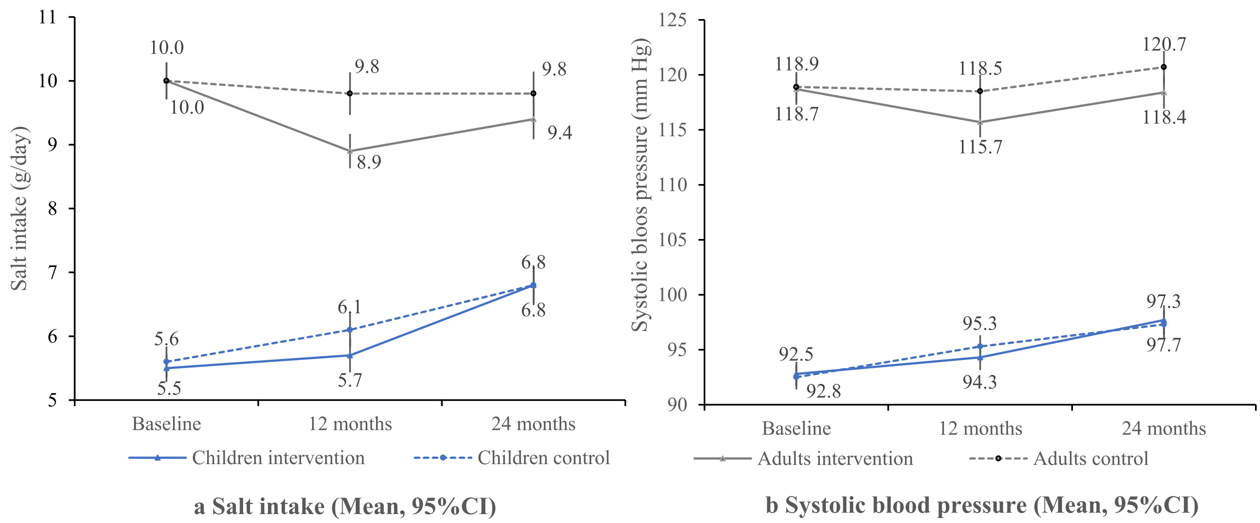

Fig. 2 Unadjusted average salt intake and systolic blood pressure by visit and group in adults and children

diminished between 6 and 36 months, even though several refresher sessions were offered to promote contact and adherence with the intervention [14]. Two other trials found similar results, though the extent of attenuation differs due to variations in participants and baseline sodium levels [15, 16]. Moreover, it was suggested that the emerging mHealth studies were privileged to sustainable intervention for healthy behavior by offering a cost and time-efficient solution in self-management and self-monitoring [9] A scoping review on the nutrition Apps in people with chronic diseases indicated that 11 out of 46 studies measured maintenance of health behavior change, of which 7 found sustained behavior change for 6 to 12 months and 4 showed a decline in behavior change or discontinued app use [24]. Our study did not specifically encourage the adherent usage of the App after the 12-month trial, which together with the discontinued motivation from schools and the unchanged food environment, possibly resulted in the poor persistence of lower salt intake of the family.

The persistent reduction of SBP observed in adults does not appear in parallel with the attenuation of salt reduction. It is likely that the effect of salt reduction continued after the trial even with the fluctuation of the salt intake, as the salt intake in the intervention group was still moderately lower than that in the control group at 24 months. Moreover, with the adult participants aging by 2 years, the SBP in the control group surpassed the baseline level, while the SBP in the intervention group remained lower than that of the baseline level. The results were in line with other population-based studies. For instance, the UK's salt reduction program led to a reduction of 1.8 g/day in population salt intake, which was associated with a fall of approximately 3 mm Hg in population SBP from 2003 to 2014. Then the salt intake in the UK rebounded from 7.68 g/day to 8.39 g/day from 2014 to 2018, whereas the SBP did not increase accordingly but plateaued during that period [17]. Similar findings were observed in the population-based studies in Finland and Iran [18, 19].

It was noteworthy that the maintenance phase of our study was right in the COVID-19 pandemic period. Most families were restricted at home, which contributed to the high follow-up rate even after 2 years of the baseline survey. However, the outbreak of COVID-19 changed the lifestyles of populations to varying extents [25, 26], which, without being measured in this study, may also potentially contribute to the changes in salt intake and SBP.

Schools have been recognized as a key setting to deliver nutrition and other health interventions to children and their parents. This school-based study did not find a significant reduction in salt intake or blood pressure in children. However, like adults, children in the intervention group still performed better in salt-related KAP scores than those in the control group even 12 months after the trial, indicating that the improvement of knowledge appeared easier than lowering salt intake, which was in line with other studies [6, 27, 28].

The strengths of our study include: first, we conducted the after-trial survey according to the standardized protocol of the trial by visiting both intervention and control groups and collecting two 24-h urine samples for all participants. The consistent protocol ensured the comparison of the three rounds of evaluations. Second, the follow-up rates were as high as 91.6%

Table 2 Salt intake, 24-h urinary measurements, blood pressure, and KAP based on intention-to-treat analysis

		Intervention		Control		Difference in change (intervention vs control)		Adjusted difference in change (intervention vs control)	
	Contrast	Adjusted difference (95% CI)[a]	*p* value	Adjusted difference (95% CI)[a]	*p* value	Difference (95% CI)[b]	*p* value	Difference (95% CI)[b,c]	*p* value
Children									
Salt intake (g/day)									
	12 months vs baseline	−0.01 (−0.31 to 0.28)	0.94	0.28 (−0.00 to 0.56)	0.05	−0.34 (−0.72 to 0.05)	0.09	−0.29 (−0.68 to 0.10)	0.14
	24 months vs baseline	0.41 (0.09 to 0.72)	0.01	0.44 (0.13 to 0.75)	0.005	0.07 (−0.32 to 0.46)	0.72	−0.04 (−0.42 to 0.35)	0.86
	24 months vs 12 months	0.42 (0.08 to 0.75)	0.01	0.16 (−0.15 to 0.47)	0.30	0.41 (0.01 to 0.80)	0.04	0.26 (−0.14 to 0.65)	0.21
Systolic blood pressure (mm Hg)									
	12 months vs baseline	0.96 (−0.40 to 2.32)	0.17	1.84 (0.55 to 3.13)	0.005	−1.23 (−2.96 to 0.50)	0.16	−0.88 (−2.65 to 0.90)	0.33
	24 months vs baseline	0.54 (−0.87 to 1.95)	0.45	1.03 (−0.38 to 2.44)	0.15	−0.01 (−1.77 to 1.74)	0.99	−0.49 (−2.26 to 1.29)	0.59
	24 months vs 12 months	−0.42 (−1.94 to 1.10)	0.59	−0.81 (−2.21 to 0.60)	0.26	1.21 (−0.55 to 2.98)	0.18	0.39 (−1.42 to 2.19)	0.67
Diastolic blood pressure (mm Hg)									
	12 months vs baseline	−0.16 (−1.33 to 1.01)	0.79	0.90 (−0.21 to 2.01)	0.11	−1.30 (−2.79 to 0.19)	0.09	−1.06 (−2.59 to 0.46)	0.17
	24 months vs baseline	−1.60 (−2.81 to −0.38)	0.01	−1.95 (−3.16 to −0.74)	0.002	0.57 (−0.94 to 2.08)	0.46	0.36 (−1.17 to 1.88)	0.65
	24 months vs 12 months	−1.43 (−2.75 to −0.12)	0.03	−2.86 (−4.07 to −1.64)	< 0.001	1.87 (0.35 to 3.39)	0.02	1.42 (−0.13 to 2.97)	0.07
Urinary sodium (mmol/24 h)									
	12 months vs baseline	−0.34 (−5.38 to 4.70)	0.90	4.74 (−0.05 to 9.52)	0.05	−5.73 (−12.3 to 0.83)	0.09	−5.08 (−11.7 to 1.57)	0.14
	24 months vs baseline	6.92 (1.59 to 12.26)	0.01	7.69 (2.41 to 12.97)	0.004	1.21 (−5.45 to 7.86)	0.72	−0.77 (−7.41 to 5.88)	0.82
	24 months vs 12 months	7.26 (1.55 to 12.98)	0.01	2.96 (−2.34 to 8.25)	0.27	6.94 (0.23 to 13.65)	0.04	4.31 (−2.46 to 11.07)	0.21
Urinary potassium (mmol/24 h)									
	12 months vs baseline	−0.14 (−1.45 to 1.17)	0.83	−0.22 (−1.47 to 1.03)	0.73	0.22 (−1.49 to 1.93)	0.80	0.08 (−1.66 to 1.82)	0.93
	24 months vs baseline	1.51 (0.15 to 2.88)	0.03	1.72 (0.36 to 3.08)	0.01	0.04 (−1.69 to 1.78)	0.96	−0.21 (−1.94 to 1.53)	0.82
	24 months vs 12 months	1.65 (0.18 to 3.13)	0.03	1.94 (0.57 to 3.31)	0.006	−0.18 (−1.93 to 1.57)	0.84	−0.28 (−2.05 to 1.49)	0.75
Sodium-to-potassium ratio									
	12 months vs baseline	0.09 (−0.19 to 0.37)	0.53	0.21 (−0.05 to 0.47)	0.12	−0.18 (−0.54 to 0.19)	0.34	−0.12 (−0.49 to 0.24)	0.51
	24 months vs baseline	0.07 (−0.23 to 0.36)	0.65	−0.01 (−0.30 to 0.28)	0.95	0.12 (−0.24 to 0.49)	0.51	0.08 (−0.29 to 0.44)	0.68
	24 months vs 12 months	−0.02 (−0.34 to 0.29)	0.89	−0.22 (−0.51 to 0.07)	0.14	0.30 (−0.07 to 0.67)	0.11	0.20 (−0.17 to 0.57)	0.30

Table 2 (Continued)

	Contrast	Intervention		Control		Difference in change (intervention vs control)		Adjusted difference in change (intervention vs control)	
		Adjusted difference (95% CI)[a]	*p* value	Adjusted difference (95% CI)[a]	*p* value	Difference (95% CI)[b]	*p* value	Difference (95% CI)[b,c]	*p* value
KAP score									
	12 months vs baseline	1.60 (1.45 to 1.75)	< 0.001	0.35 (0.20 to 0.51)	< 0.001	1.25 (1.04 to 1.46)	< 0.001	1.25 (1.04 to 1.46)	< 0.001
	24 months vs baseline	1.60 (1.45 to 1.75)	< 0.001	0.80 (0.65 to 0.95)	< 0.001	0.80 (0.58 to 1.01)	< 0.001	0.80 (0.59 to 1.01)	< 0.001
	24 months vs 12 months	−0.00 (−0.15 to 0.15)	0.97	0.45 (0.29 to 0.60)	< 0.001	−0.45 (−0.67 to −0.24)	< 0.001	−0.45 (−0.66 to −0.23)	< 0.001
Adults									
Salt intake (g/day)									
	12 months vs baseline	−1.01 (−1.32 to −0.69)	< 0.001	−0.18 (−0.48 to 0.12)	0.23	−0.88 (−1.30 to −0.47)	< 0.001	−0.83 (−1.25 to −0.41)	< 0.001
	24 months vs baseline	−0.67 (−0.99 to −0.35)	< 0.001	−0.29 (−0.61 to 0.02)	0.06	−0.35 (−0.77 to 0.08)	0.11	−0.38 (−0.81 to 0.05)	0.09
	24 months vs 12 months	0.34 (−0.03 to 0.71)	0.07	−0.11 (−0.45 to 0.22)	0.51	0.54 (0.11 to 0.97)	0.02	0.45 (0.01 to 0.89)	0.05
Systolic blood pressure (mm Hg)									
	12 months vs baseline	−1.35 (−2.40 to −0.29)	0.01	0.45 (−0.54 to 1.45)	0.37	−2.51 (−3.90 to −1.11)	< 0.001	−1.80 (−3.19 to −0.40)	0.01
	24 months vs baseline	−0.88 (−1.93 to 0.18)	0.10	1.32 (0.28 to 2.36)	0.01	−2.09 (−3.53 to −0.64)	0.005	−2.19 (−3.63 to −0.76)	0.003
	24 months vs 12 months	0.47 (−0.77 to 1.71)	0.46	0.87 (−0.25 to 1.98)	0.13	0.42 (−1.04 to 1.88)	0.57	−0.40 (−1.86 to 1.07)	0.60
Diastolic blood pressure (mm Hg)									
	12 months vs baseline	−1.00 (−1.72 to −0.28)	0.007	−0.32 (−0.99 to 0.36)	0.36	−1.16 (−2.11 to −0.21)	0.02	−0.68 (−1.64 to 0.27)	0.16
	24 months vs baseline	−0.98 (−1.70 to −0.26)	0.007	−0.42 (−1.13 to 0.29)	0.24	−0.46 (−1.45 to 0.52)	0.36	−0.56 (−1.54 to 0.41)	0.26
	24 months vs 12 months	0.02 (−0.83 to 0.86)	0.97	−0.11 (−0.86 to 0.65)	0.79	0.70 (−0.30 to 1.69)	0.17	0.12 (−0.88 to 1.12)	0.81
Urinary sodium (mmol/24 h)									
	12 months vs baseline	−17.2 (−22.6 to −11.8)	< 0.001	−3.12 (−8.24 to 2.00)	0.23	−15.1 (−22.2 to −8.04)	< 0.001	−14.1 (−21.3 to −6.95)	< 0.001
	24 months vs baseline	−11.5 (−16.9 to −6.07)	< 0.001	−5.03 (−10.4 to 0.29)	0.06	−5.90 (−13.2 to 1.41)	0.11	−6.44 (−13.8 to 0.91)	0.09
	24 months vs 12 months	5.77 (−0.56 to 12.10)	0.07	−1.92 (−7.63 to 3.79)	0.51	9.22 (1.81 to 16.63)	0.02	7.69 (0.14 to 15.24)	0.05
Urinary potassium (mmol/24 h)									
	12 months vs baseline	−0.49 (−1.76 to 0.78)	0.45	−0.53 (−1.72 to 0.67)	0.39	0.11 (−1.54 to 1.76)	0.90	0.03 (−1.65 to 1.71)	0.90
	24 months vs baseline	−0.12 (−1.39 to 1.14)	0.85	−0.73 (−1.98 to 0.52)	0.25	0.55 (−1.15 to 2.25)	0.53	0.60 (−1.12 to 2.33)	0.49
	24 months vs 12 months	0.37 (−1.12 to 1.85)	0.63	−0.20 (−1.54 to 1.14)	0.77	0.44 (−1.29 to 2.16)	0.62	0.57 (−1.20 to 2.34)	0.53
Sodium-to-potassium ratio									
	12 months vs baseline	−0.32 (−0.47 to −0.16)	< 0.001	−0.05 (−0.19 to 0.10)	0.55	−0.30 (−0.51 to −0.10)	0.004	−0.27 (−0.48 to −0.06)	0.01
	24 months vs baseline	−0.19 (−0.34 to −0.03)	0.02	−0.07 (−0.22 to 0.09)	0.39	−0.10 (−0.31 to 0.11)	0.35	−0.12 (−0.33 to 0.09)	0.27
	24 months vs 12 months	0.13 (−0.05 to 0.31)	0.16	−0.02 (−0.19 to 0.14)	0.81	0.20 (−0.01 to 0.41)	0.07	0.15 (−0.07 to 0.37)	0.18

Table 2 (Continued)

	Contrast	Intervention		Control		Difference in change (intervention vs control)		Adjusted difference in change (intervention vs control)	
		Adjusted difference (95% CI)[a]	*p* value	Adjusted difference (95% CI)[a]	*p* value	Difference (95% CI)[b]	*p* value	Difference (95% CI)[b,c]	*p* value
KAP score									
	12 months vs baseline	1.04 (0.91 to 1.17)	< 0.001	0.23 (0.09 to 0.36)	< 0.001	0.81 (0.62 to 1.00)	< 0.001	0.81 (0.62 to 1.00)	< 0.001
	24 months vs baseline	1.37 (1.23 to 1.51)	< 0.001	0.75 (0.61 to 0.89)	< 0.001	0.62 (0.43 to 0.82)	< 0.001	0.62 (0.43 to 0.82)	< 0.001
	24 months vs 12 months	0.33 (0.19 to 0.47)	< 0.001	0.52 (0.38 to 0.66)	< 0.001	− 0.18 (− 0.38 to 0.02)	0.07	− 0.19 (− 0.39 to 0.01)	0.07

KAP Knowledge, Attitude, and Practice, *CI* confidence interval

[a] Comparison of the means between baseline, 12-month follow-up, and 24-month follow-up. Positive values = increases from baseline to 12/24-month follow-up; negative values = reductions from baseline to 12/24-month follow-up

[b] Comparison between intervention and control groups in the changes from baseline to 12/24-month follow-up. Positive values = the intervention group had a greater increase or less decrease from baseline to 12/24-month follow-up than the control group; negative values = the intervention group has a greater decrease or smaller increase from baseline to 12/24-month follow-up than the control group

[c] Adjusted for age, sex, body mass index (body weight in children instead), outdoor temperature, study site, highest education level in the family; blood pressure values were further adjusted for physical activity and alcohol consumption in adults only

for children and 82.4% for adults even 24 months after the baseline, which would avoid potential bias caused by high drop-out rates.

Our study also has limitations. First, as we only collected the measurements at 24 months rather than monitoring the trend of salt intake and blood pressure at multiple times, the one measurement may not fully reflect the change pattern of salt intake and blood pressure. Second, we did not collect the intervention data after the completion of the trial, which might contribute to the difference between the two groups. However, the intervention packages were expected not to be adopted by schools of both intervention and control groups during the COVID-19 pandemic, which were confirmed by several informal interviews with teachers when conducting the follow-up survey. Neither did we collect other confounding factors that might affect the dietary intake and blood pressure of the participants, such as the management of the blood pressure and the possible change of dietary and living habits under the COVID-19 pandemic. Third, the KAP questionnaire was self-reported, which may bring about information bias.

In summary, high blood pressure is an important public health problem worldwide leading to an estimated 10.8 million avoidable deaths every year [29]. The sustained lower SBP found in this study showed the potential of the persistent effect of salt reduction intervention on the control of blood pressure, though further research is needed to explore the reason behind the persistence. The relapse of the salt intake suggested that more effort is warranted to maintain a lower salt intake in the population after intensive interventions stop. The findings from this study supported the importance of a healthy food environment in facilitating healthier dietary choices of individuals. With digital health evolving rapidly, the innovative intervention strategy could provide stronger support for continuous behavior change by integrating the behavior change model with advanced techniques. Moreover, potassium-enriched salt substitutes could serve as another feasible strategy to support salt reduction in the population along with behavior change intervention through education [30].

Conclusions

In this 1-year follow-up after the cluster randomized clinical trial, the effect of the education program on adults' salt intake faded, but the reduction of SBP and the improvement of KAP score remained 12 months after the RCT. There is potential for the lasting impact of the salt reduction intervention on blood pressure control. Efforts aimed at reinforcing a supportive environment, innovative technology, and viable strategy are needed to maintain lower salt intake in real-world settings.

Abbreviations

RCT	Randomized controlled trial
KAP	Knowledge, Attitude, Practice
CI	Confidence interval
SD	Standard deviation
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
app	Application

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-03868-8.

Additional file 1. Table S1. Salt-related Knowledge, Attitude and Practice (KAP) score for adults. Table S2. KAP score for children. Table S3. Average salt intake, 24-h urinary measurements, blood pressure and KAP by treatment and visit in children and adults. Table S4. Sample size of primary analysis and sensitivity analysis. Table S5. Sensitivity analysis for salt intake (g/day) as calculated from 24-h urinary sodium excretion. Table S6. Sensitivity analysis for systolic blood pressure (mm Hg). Table S7. Treatment difference of salt intake (g/day) as measured by 24-h urinary sodium excretion by subgroup. Table S8. Treatment difference of systolic blood pressure (mm Hg) by subgroup. Figure S1. Treatment difference of salt intake and systolic blood pressure by subgroup with 24-month follow-up vs baseline.

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Authors' contributions

PZ, FJH, YL, RL, JS and CW designed the study, developed the protocol, and were involved in the interpretation of the results. YL, RL, FC, WZ, YZ, HC, TW, XW, HZ, ZH, and JZ were responsible for the onsite field investigation and supervision of data collection. YL and JS performed statistical analyses of the study. All authors had full access to the data in the study, YL and PZ accessed and verified all data. YL wrote the first draft of the manuscript, and all authors contributed to the revision. PZ and FJH received the funding and are the guarantors. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. All authors read and approved the final manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the Queen Mary (University of London) Ethics of Research Committee (QMERC2018/13) and the Peking University Institutional Review Board in China (IRB00001052-18051). Permissions were obtained from the local education authorities and school headteachers. All participants who took part in the outcome assessments gave written informed consent. For children, participant assent and parental written consent were obtained.

Consent for publication

Not applicable.

Competing interests

FJH is an unpaid member of Action on Salt and World Action on Salt, Sugar and Health (WASSH); no other relationships or activities that could appear to have influenced the submitted work. All other authors declare no competing interests.

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