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Poyen Liu Date

A four-year mixed family- and community-based growth monitoring and promotion program for children with undernutrition up to five years in Cambodia.

By

Poyen Liu
Degree to be awarded: Master of Public Health

Executive MPH

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M.D.
Chung Shan Medical University
1999

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An abstract of
A thesis submitted to the Faculty of the Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
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Abstract

A four-year mixed family- and community-based growth monitoring and promotion program for children with undernutrition up to five years in Cambodia.

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Undernutrition of children is a major public health problem in developing countries. Children especially under 1 year suffering from undernutrition have physical and neurological consequences. Growth monitoring and promotion program has been designed for decades to tackle this issue in developing countries. However, the prevalences of undernutrition in developing countries are still challenging, nevertheless.

We conducted a comprehensive community-based growth monitoring and promotion program targeting children under five years in a Cambodian rural village from 2016 through 2019. This program was equipped with a hybrid of full-time health workers and community volunteers. Through ample workforce capacity, we provided nutrition education sessions in a small group setting, family-centered nutrition counseling, and frequent anthropometric measurements. Instead of a cross-sectional approach, we used multi-level growth modeling to analyze our longitudinal z scores for height-for-age and weight-for-age. We dichotomized our children into two groups for comparison: under one year and above one year.

The result showed that growth trajectory of children under one year was different from growth patterns normally observed in developing countries. We also found that a longer duration of growth monitoring and promotion program was related to a better nutrition outcome.

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Table of Contents

Introduction

Growth Faltering in children, especially during the first 1000 days of life, causes short-term and long-term consequences. The short-term consequences include increasing risk of morbidity, mortality, and neural cognitive development during childhood. The long-term undernutrition status impacts attainment of human capital and economic loss.(1-6) After years of efforts to eliminate childhood undernutrition in low- and middle-income countries, growth faltering remains a major public health challenge in ow-income countries.(7-14) Globally, 149.2 million children under-five (22.0%) were stunted while another 45.4 million children (6.7%) were wasted in 2020.(15) With this persistent high prevalence of undernutrition in children around the world, we still need effective strategies to mitigate the burden of undernutrition.

Growth monitoring and promotion (GMP) has been widely leveraged to avert decline of childhood growth trajectories worldwide in decades since it was first proposed in the 1970s.(16) World Health Organization (WHO) released a guideline in 2017 advocating GMP as part of its efforts to tackle child malnutrition. (17) Regular anthropometric measurements, detection of growth faltering, nutritional counseling/interventions are core elements of a GMP. Regular anthropometric measurements are usually carried out at local public health facilities and/or community levels. Child growth standards have been updated several times for anthropometric measurements reference since its emergence in the 1970s. Currently, WHO child growth standards, based on multi-country child growth pattern, serve as a representative reference for charting of child growth curve under five years. By referencing WHO child growth standard, the actual body height and weight from anthropometric measurements would be converted into height-for-age *z* score (HAZ) and weight-for-age *z* score (WAZ) respectively. Stunting and wasting, derive from *z* score conversion, provide an objective evaluation about a child's nutrition status quo. Stunting, defined as HAZ $\geq$2

SDs below the median, implies chronic malnutrition of a child. Wasting, defined as WAZ ≥2 SDs below the median, reflects short-term nutrition deficiency. Stunting and wasting are two most commonly objective indicators for evaluation of nutritional status quo and advancement of nutrition progress in a child. Growth faltering could be detected in time by regular anthropometric measurements. Once signs of growth faltering are noticed, follow-up activities with interventions and nutrition counseling for caregivers would be triggered in the hope of reversing growth trajectory downturn.

However, the effectiveness of GMP delivery to combat childhood undernutrition remains unclear although it has been implemented in different developing countries across the world for decades.(18-21) A GMP needs a well-coordinated operation of its core elements. Anthropometric measurement itself could not lead to a health improvement. The follow-up activities are the key to turn around the health status of a child. So far, there is no clear definition of what interventions should be included in a GMP. The range of follow-up interventions/activities has a wide spectrum, and the interventions in different communities could take different forms. Perception of GMP by policymakers and scarcity of resources also impact the scale of interventions conducted in a GMP. Low coverage/participation rate, weak implementation, poor linkage between poor organizational structure of child health programs, staff shortages, and inadequate staff training and monitoring are those ever mentioned responsible for poor effectiveness of a GMP.(18-22)

Based on some studies published, the HAZ and WAZ in developing countries characterize a unique pattern in the first 5 years of life. The HAZ at birth generally range from 0 to -2 across developing countries. The HAZ declines continuously after birth and reaches a nadir in 24-36 months. On the other hand, the WAZ at birth ranged from 0 to -2 across developing countries and hovers at the same level without declining in the first 5 years.(23-31) This distinctive feature of

HAZ/WAZ trajectories in developing countries gives rise to potential pitfalls in a GMP setting. GMP duration and age range of enrolled children might interfere with the outcomes of a GMP. If duration of a GMP ranged only 24 to 48 months, it might not be able to capture the entire HAZ fluctuations in the first 5 years of life. On top of that, a GMP with participants under 2 years might have different outcomes with participants with age ranging from 2 to 5 years old.

Cambodia is a low-income country with high prevalence of childhood undernutrition. (7, 32-37) There is an urgent need to address the undernutrition issue in Cambodia. The growth trajectories of Cambodian children are no different from those in other developing countries. (25, 28, 29, 38-41) Among Cambodia children, HAZ at birth is negative and reaches its nadir at 24 months and the WAZ at birth is negative and does not fluctuate much during the first 5 years of life. To narrow the gap between GMP theories and its practical application, we conducted a prospective GMP in a Cambodian rural village. The duration of the GMP was lengthened to 4 years, which is longer than most of the past GMPs. We hope a longer GMP span might be capable of delineating a comprehensive growth curve of children in developing countries. To overcome staff issues, we hired 4 local staff for anthropometric measurements to avoid erroneous anthropometric measurements and ensure data consistency and correctness. Anthropometric measurements were conducted in several locations proximal to households in the community to increase coverage rate and decrease missing data. To increase contact of caregivers with health providers, local staff visited households periodically to provide nutrition counseling for caregivers. During these visits, demographic factors will be obtained for further referential analysis. Our longitudinal data was processed in a linear mixed effect model instead of a cross-sectional approach. The linear mixed effect model is the best fit for longitudinal repeated data as it explains within-person change and between-person differences in change over time instead of the average change of a specific population. (42-46)

Demographic factors would be further added into our model for referential analysis.

Methods

Setting

This GMP was implemented in Pot Sar commune from August 2017 through 2020 December by Kaohsiung Veterans General Hospital. Pot Sar commune is located in Takeo province, Cambodia. Takeo province is one of the poorer provinces of this country. Pot Sar commune has 11 villages with population size of 13,519 in 2019. Before implementation of this GMP, Kaohsiung Veterans General Hospital had partnered with Green Umbrella for years. Green Umbrella is a non-government organization based in Pot Sar commune and had been engaged in children education and health care in this community since 2012. The hospital also had a partnership with Bati Referral Hospital for improving health care quality. Through these two local institutions, we could gain access to this relatively isolated community.

Children eligible for this study were below 5-years-old living in Pot Sar commune. Children with severe pre-existing medical conditions were excluded from this study. We recruited participants and local volunteers through Green Umbrella as it has been serving children in this community for years. After informed consent was obtained, children were recruited into this program. Initially, 168 children entered this program in August 2017. Another 131 children entered this program in April 2018. At last, 62 children were enrolled in the project in October 2018. At last, a total of 361 children were included in this program. Four local employees were hired as case managers for anthropometric measurements, education sessions, and home visit. A full-time pediatrician from Kaohsiung Veterans General Hospital was stationed in this community for coordination and supervision of the four case managers. After recruitment, the four case managers received a 5-day-long training session in advance of the GMP. The training courses focused on skills of communication, anthropometric measurement, and nutrition knowledge. Each case manager was equipped

with a laptop for storage of anthropometric and demographic data. We organized a Pot Sar children nutrition improvement committee to incorporate local political leaders into this program. The members of this committee included the leader of Pot Sar commune, local leaders from the 11 villages, the superintendent of Pot Sar health care clinic, and the founder of Green Umbrella. Committee meetings were held monthly during the GMP period. Stationed pediatrician and case managers attended this meeting and presented last month's work and progress to the committee members. Future events in the coming month were announced in this meeting to the stakeholders. We recruited 32 volunteers across the 11 villages to coordinate with the four case managers. The 32 volunteers attended a 5-day nutrition knowledge training annually during the 4-year program period. The 361 children were divided into 32 small groups in terms of proximity with 15-20 children in each group. The 32 volunteers were allocated to the 32 groups with one volunteer in each group. Each volunteer worked closely with the case managers for coordination of the anthropometric measurements and nutrition education sessions.

Nutrition education sessions

We conducted nutrition education sessions in every single small group. We designed a "loyalty stamp and punch card" for attendees to boost turnout. Incentives with nutrition supplements would be provided if caregivers reached attendance thresholds. We anticipated that a small group setting would create an intimate environment and provide mutual communications between caregivers and health workers. The venues of nutrition education sessions were set up in volunteers' houses with proximity to caregivers' homes. The education sessions took place across the 32 small groups every 3 months. The education session covered a wide range of contents that caregivers would encounter during child raising introduction of three macronutrients, breastfeeding, timing of starting complementary feeding, personal hygiene including hand wash skills, environmental sanitation, food and drinking water safety, common health issues in this age group, importance of vaccination card, and procedures about anthropometric measurements. Given the high rates of illiteracy in this community, we structured the education session in the form of a game format. A game

format could create an interactive and competitive environment for caregivers to bolster their active learning. The contents of an education session would be transformed into pictures and illustrations in a brochure for caregivers to review at home. To boost awareness of nutrition importance, three huge tarps with advertisement were put up near major roads of this community to captivate residents' attention.

Interventions

Deworming and vitamin A supplement has been a routine service by the Pot Sar health care clinic before our GMP. However, the coverage rate of deworming drugs and vitamin A supplements before our GMP were only 73.5% and 83% respectively. To increase coverage rate, we reiterated the importance of deworming and vitamin A supplements to the stakeholders in the Pot Sar children nutrition improvement committee. We proposed that, besides immunization records, history of deworming administration should be marked on the existing immunization card by Pot Sar health care clinic. We would administer deworming drugs to children if we noticed no deworming remark on their vaccination cards when they took anthropometric measurement. We tweaked local recipes to incorporate more local-grown ingredients and nutrients into the local diet. We demonstrated the new recipes to the 32 volunteers first. We then debuted these new dishes in several social events for the caregivers to sample. We had cooking sessions led by volunteers for anticipants in these events. These modified recipes would be distributed across the community in a pamphlet. For the convenience of caregivers preparing food at home, we created a visual aid tool for caregivers. The special visual aid had three illustrations representing three macronutrients: carbohydrate, protein, and fat. The size of the three illustrations matched the size of serving portions of each macronutrient required for a meal. The visual aid was printed onto a water-proof plastic plate for the use in a kitchen. This plate would facilitate caregivers to provide an ample and balanced meal for their children. We composed a hand washing song with choreography and demonstrated it in every education session. This would help keep children engaged so they would practice hand washing in their daily hygiene routine.

Home visits were the foundation of intervention in our GMP. Nutrition counseling was provided to all caregivers participating at the household level. Case managers along with volunteer visited caregivers monthly. Case managers utilized a structured questionnaire to guide their interview with caregivers. The

structured questionnaire was based on the contents of nutrition education sessions. During home visits, case managers provided tailored responses to caregivers' questions based on different contexts. Case managers evaluated the extents of behavior changes firsthand. Case managers reiterated nutrition knowledge to caregivers if they deemed necessary. Assessment of household sanitation was conducted during the home visit, and recommendations were given to the caregivers. Reinforcement of nutrition knowledge ensured that caregivers would reshape their diets and sanitation habits eventually.

Anthropometric measurements

For caregivers' convenience, anthropometric measurements took place immediately after education sessions at the same places. As each small group only had 15 to 20 children, we could decrease burden of health workers and decreased errors of anthropometric data. Anthropometric data were measured using weight scale and standing height scale. For infants or toddlers who could not stand alone, we used length boards and calibrated Salter hanging infant weighing scale for measurement. All measurement instruments were calibrated before each measurement session. All measurements were performed twice. If children did not attend these measurement sessions, the weight and height data were obtained through home visits. Data were inputted into case managers' laptops on the same day of measurements.

Collection of Demographic information

The data were collected using a structured questionnaire via face-to-face interviews by case managers during home visits. The questionnaire was designed to capture the sociodemographic and economic characteristics of the families. The sociodemographic information included: age, gender, birthday, numbers of siblings, birth order, pre-existing medical conditions, main caregivers (parents, grandparents, other), minor caregivers, vaccination adherence (yes, no), deworming drugs adherence (yes, no), vitamin A supplement (yes, no), IDPoor card (yes, no), expense on food each day (<$2.5, $2.5-$5, >$5), who prepares the food (father, mother, grandparents), mother's education degree (none, grade school, middle school, high school, college), , water sources (tap water, well water, fresh/rainwaters, others), boiling/filtering water before drinking (yes, no).

IDPoor card was issued by Cambodian government as part of its effort to eliminate poverty in this country.

Households had to complete a Ministry of Planning's standard questionnaire for eligibility. The questionnaire consists of a set of proxy indicators for poverty, which are mainly based on easily observable and verifiable household characteristics such as assets, household size or education status.

Statistical methods

The categorical indicators such as gender were presented in proportion with the number of observations. The distribution between groups was tested with a Chi-square test for multiple proportions. Ordinal variables, such as age and number of children in the household, were represented through mean and standard deviation. The tests applied were student t-tests for continuous variables with a two-sided P value < 0.05 regarded as significant.

For data processing, we converted actual weight and height of each participant to corresponding weight-for-age (WAZ) and height-for age z-scores (HAZ). Nutritional Survey function in WHO Anthro software was used for the z scores conversion. We did not have a control group in our study. Based on previous studies that HAZ of children declined continuously after birth for the first two years in developing countries, we separated our study group into two subgroups in terms of their ages: under 12 months, and above 12 months (AGE1). Based on length of follow-up in this GMP, we created a dichotomized variable as a control predictor: FOLLOWPERIOD. If children entered our GMP in the beginning of our GMP, the FOLLOWPERIOD was coded as one, otherwise it was zero. In this way, we could find out whether our GMP averted the declining HAZ trajectories among children under one year and compare it with children above one year controlled by time length of follow-up. To identify important features of growth curve of our study population, we conducted an exploratory data analysis first. We used both ordinary least square regression method (OLS) and smooth nonparametric trajectories for our exploratory analysis. The second group of children entered the program at the fifth anthropometric measurement, and their first measurement was to be compared with the corresponding first Anthropometric measurement from the children who entered the program in the beginning. Likewise, the third group of children entered this GMP at 8^{th} anthropometric measurement and their first measurement was compared with corresponding first measurement of children who enter this GMP in the beginning. Ordinary least square regression method (OLS) also estimated the

intercept and slope of HAZ and WAZ in our study populations. We also explored parameters of HAZ and WAZ in the two subgroups. Through OLS, the average trajectory of a continuous longitudinal variable was graphed for further linear mixed modeling. For smooth nonparametric trajectories, instead of only two age groups, we further divided our participants into three subgroups: under 12 months, between 12 and 24 months, and above 24 months. The nonparametric growth curves of the three subgroups were plotted for comparison. These visual graphical analyses gave us a general picture of growth pattern of our whole study group and subgroups and prepared us for subsequent model-based analyses.

Weight and height were measured repeatedly over time within each individual participant. The serial measurements of HAZ and WAZ within the individual were correlated to each other. In this case, multilevel modeling (MLM) fitted the longitudinal data best, as it allowed us to address within-person and between-person questions about change simultaneously. In an MLM, level-1 represented within-person change and level-2 represented between-persons change. In MLM, we introduced random effects into our model and allowed the regression coefficients of HAZ and WAZ to vary between subjects. Maximum likelihood (ML) method was used to estimate the coefficients of an MLM.

We fitted the unconditional means model (model A) first. In model A, we assumed the trajectories of HAZ and WAZ were flat without predictors. There was one fixed parameter (γ_{00}) and two random parameters ($\sigma_0^2, \sigma_\epsilon^2$) in model A. In model A, the fixed effect, γ_{00}, estimated grand mean of HAZ and WAZ across all anthropometric measurements and individual children. The variances σ_0^2 and σ_ϵ^2 were between-person and within-person variance, respectively. If γ_{00} was not zero, we confirmed that the average HAZ and WAZ were not zero during the 16 anthropometric measurements. In model A, intraclass correlation coefficient ρ was defined as $\sigma_0^2 / (\sigma_0^2 + \sigma_\epsilon^2)$, and it represented proportion of between-individual variation in total variation. If the interclass correlation coefficient was not zero, we confirmed that it was worth proceeding to the next logical step: unconditional growth model (model B).

In model B, we introduced serial anthropometric measurements (WAVE) into the level-1 submodel. There were 2 fixed parameters (γ_{00}, γ_{01}) and 4 random variances ($\sigma_\varepsilon^2, \sigma_0^2, \sigma_1^2, \sigma_{01}^2$) in model B. The fixed

effects, γ_{00} and γ_{01}, estimated the start point and slope of the average HAZ and WAZ change trajectory. The σ_0^2 and σ_1^2 now summarized between-person variance in initial status and rate of anthropometric change. The difference of σ_ε^2 between model A and B estimated the proportion of within-person variation associated with serial measurement. We used full or restricted maximum likelihood methods to compare the fitness of model A and model B. The deviance of -2 Res Log Likelihood (-2RLL) in each model was compared with approximate chi-square distribution when we used the maximum likelihood method.

After we recognized model A was nestled in model B, we added the variable AGE2 into model B to make model C and address our research questions. In model C, AGE2 as the question predictor explained variation in individual initial status or rate of change of HAZ and WAZ in the 2-level model. Based on deviance of -2RLL between model b and C, we decided whether model C was superior to model B. In model D, we added FOLLOWPERIOD into model C as a control predictor. We had 6 fixed effects in model D: Υ_{00}, Υ_{01}, Υ_{02}, Υ_{10}, Υ_{11}, and Υ_{12}. In model D, the Υ_{01} and Υ_{11} described the differential in HAZ and WAZ between children under 2 years and above 2 years while controlling for effects of length of follow-up time. We compared deviance of -2RLL between model D and C to decide which model better fitted our data.

Results

A total of 358 children were included in this GMP. 167 children were enrolled when the GMP started. 150 children entered this GMP at the fifth wave of anthropometric measurement. Another 41 children entered this program at the eighth wave of anthropometric measurement. There were 16 anthropometric measurements in total conducted during the 4-year GMP period.

136 children were younger or equal one-year-old, and 222 children were older than one year. Gender distributions between the two groups were not significantly different. Some demographic factors differed between the two age groups. The group of children older than 1 year had a significantly lower initial HAZ and WAZ than children younger than 1 year. However, at the end poaint, HAZ and WAZ between the two groups were not different. Proportions of stunting and wasting at the start point were significantly higher in the older group. However, at end of the 16 measurements, the percentage of wasting and stunting were no different between the two groups. (Table 1.)

Table 2 reveals demographic characteristics and is stratified by the two groups. Some demographic characteristics had significant disparities between the young and old groups. Proportion of mother as caregiver was higher in the younger group. Proportion of deworming drug administration and vitamin A supplement were lower in the younger group. Vaccine conformity was higher in the older group. More families in the younger group boiled water before drinking. For the rest of demographic characteristics, there were no notable variations observed.

Figure 1 depicts nonparametric HAZ trajectories stratified by the three age groups.

Figure 1A is the HAZ trajectory of children under 12 months. The HAZ trajectory had a higher initial status than the other two age groups with a declining trajectory reaching its nadir at 2nd wave of anthropometric measurement. Figure 1B is HAZ trajectory of children between 12 and 24 months. The initial HAZ was lower than the youngest group with a declining trajectory turning around at first anthropometric measurement. Figure 1C is the trajectory of children above 24 months. Although the initial HAZ status was lower than the youngest group, but its slope of growth curve was relatively flat without an initial downturn.

Figure 2 depicts nonparametric WAZ trajectories stratified by the three age groups. Figure 2A is the WAZ trajectory of children under 12 months. The initial WAZ was higher than the other two older age groups with a fluctuating curve across the 16 anthropometric measurements. Figure 2B and 2C represent growth trajectories of children between 12 and 24 months and above 24 months, respectively. Compared with the youngest group, the initial WAZ was lower, and the curves were relatively flat.

Table 3 reveals the taxonomy of statistical models fitted to the serial WAZ data. In model A, Υ_{00}, the grand mean of WAZ across different measurements and individual children, was -1.19. The σ_ε^2 and σ_0^2 were 0.21 and 0.76, respectively. By rejection of the null hypothesis, all three estimates, Υ_{00}, σ_ε^2, and σ_0^2, were significant. The ρ, interclass correlation coefficient defined by $\sigma_0^2 / (\sigma_0^2 + \sigma_\epsilon^2)$, was 0.78.

In model B, the two fixed effect parameters Υ_{00} and Υ_{10} were -1.20 and 0.002, respectively. The trajectory is depicted in Figure 2 with an intercept of -1.20 and a slope of 0.002. The two random effect parameters σ_ε^2 and σ_0^2 were 0.12 and 1.00, respectively. σ^2_ε decreased from 0.21 in model A to 0.12 in model B, which meant 43% of within-person variation in WAZ was associated with anthropometric measurements. The results of non-zero variability in true initial WAZ status, true rate of WAZ change, and significant deviance of -2RLL between model A and B suggested us to introduce a level-2 predictor, our research question, in model C to explain heterogeneity in each parameter.

In model C, the research predictor (AGE1) was added into the model. The initial status WAZ values of children under 1 year and above 1 year were -0.92 and -1.37. The slope of WAZ values for under 1 year and above 1 year were -0.02 and 0.2. The trajectories are depicted in Figure 3. All the four fixed effects parameters were significant in model C. The values of the four random variances remained the same in model C as in model B. The deviance of -2RLL between model B and C was significantly different and model C explained more variability of WAZ change than the model B.

In model D, we added our control predictor FOLLOWPERIOD into model C. Among the 6 fixed effects parameters of model D, Υ_{00}, Υ_{01}, Υ_{10}, and Υ_{11} were significant. However, Υ_{02} and Υ_{12} were not significant. All the random effects were significant, but compared with model C, the values did not further decline. The

deviance of -2RLL between model D and C was not significant. Therefore, model D did not better fit the WAZ data than model C.

Table 4 reveals the taxonomy of statistical models fitted to the serial HAZ data. In model A, Υ_{00}, the grand mean of HAZ across different measurements and individual children, was -1.27. The σ_ε^2 and σ_0^2 were 0.33 and 0.80, respectively. By rejection of the null hypothesis, all three estimates, Υ_{00}, σ_ε^2, and σ_0^2 , were significant. The ρ, interclass correlation coefficient defined by $\sigma_0^2 / (\sigma_0^2 + \sigma_\epsilon^2)$, was 0.70.

In model B, the two fixed effect parameters, Υ_{00} and Υ_{10}, was -1.37 and 0.01, respectively. The trajectory is depicted in Figure 2 with an intercept of -1.37 and a slope of 0.01. The two random effect parameters, σ_ε^2 and σ_0^2 were 0.17 and 1.38, respectively. σ^2_ε decreased from 0.33 in model A to 0.17 in model B, which meant 49% of within-person variation in HAZ was associated with anthropometric measurements. The non-zero initial HAZ status and rate of HAZ change and significant deviance of -2 Res Log Likelihood (-2RLL) between model A and B suggested us to introduce a level-2 predictor into model B to explain heterogeneity in each parameter.

The research predictor AGE1 was introduced into the model C. Initial HAZ values of children under 1 year and above 1 year were -1.08 and -1.54, respectively. The slope of HAZ values for under 1 year and above 1 year were -0.006 and 0.03, respectively. The trajectory is depicted in Figure 4. Among fixed effects parameters, Υ_{10} was the only insignificant parameter. Compared with model B, the values of four random variances of model C remained the same but were still significant. The deviance of -2RLL between model B and C was significant.

In model D, we introduced FOLLOWPERIOD for controlling AGE1. All 6 fixed effects and four random effect variances were significant. The deviance of -2RLL between model D and C was significant. Model D better fitted the HAZ data.

Table 5 was the taxonomy of multilevel models for change fitted to the WAZ and HAZ data.

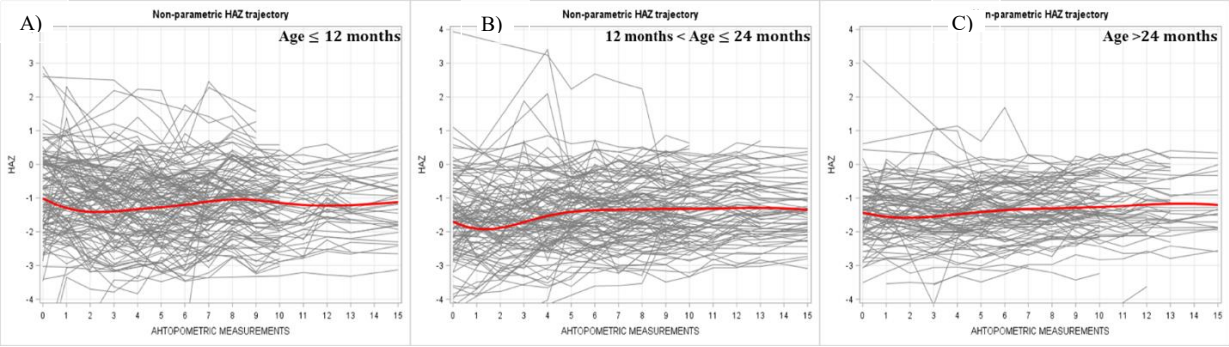

Figure 1 Individual and Average HAZ trajectory stratified by age across different measurements (Bold red line represented the average trajectory for the whole group)

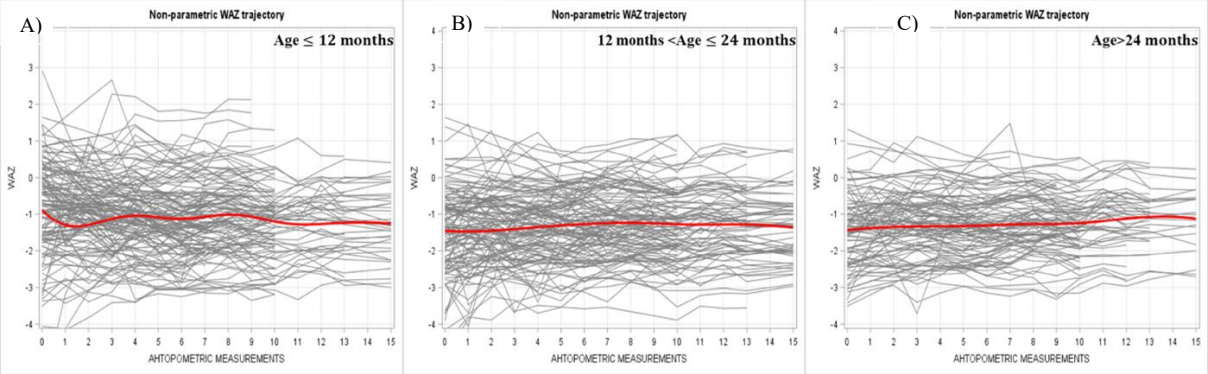

Figure 2 Individual and Average WAZ trajectory stratified by age across different measurements (Bold red line represent ted the average trajectory for the whole group)

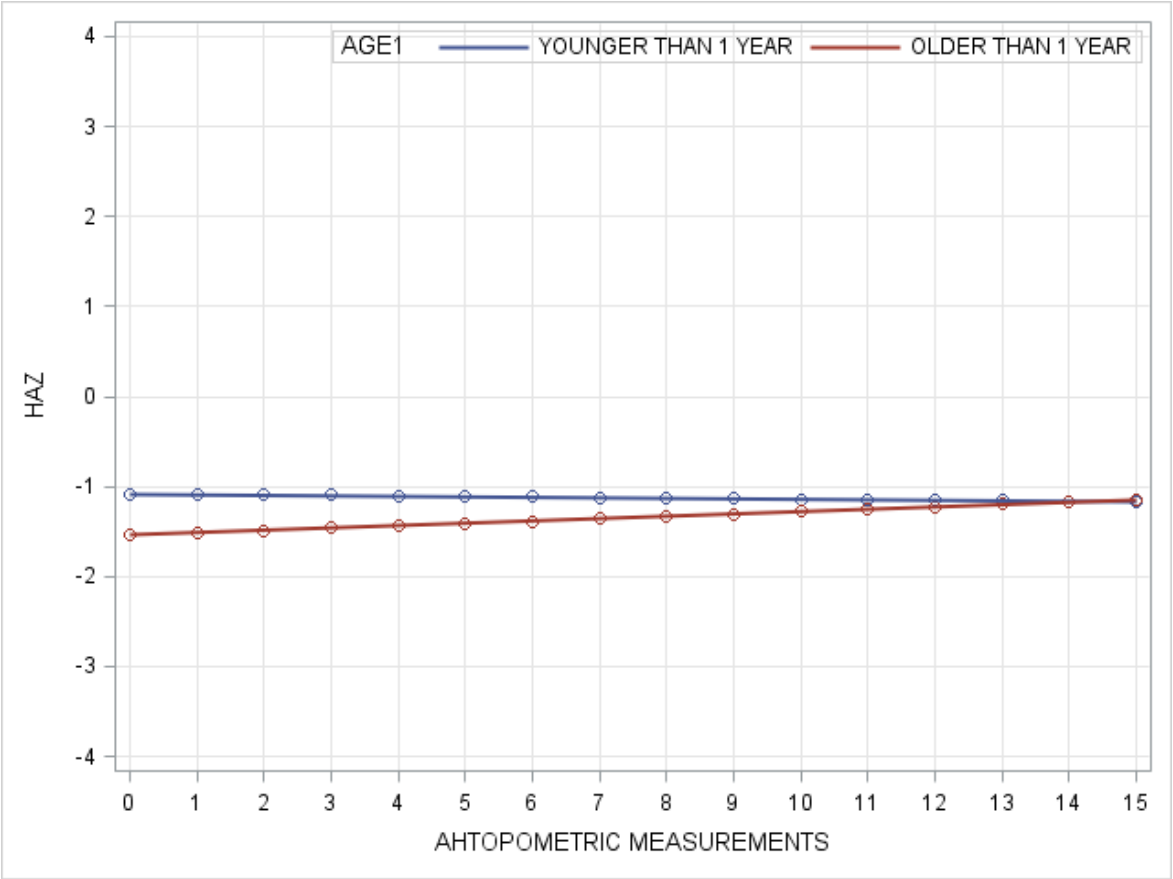

Figure 3 Result of fitted HAZ trajectories for model C

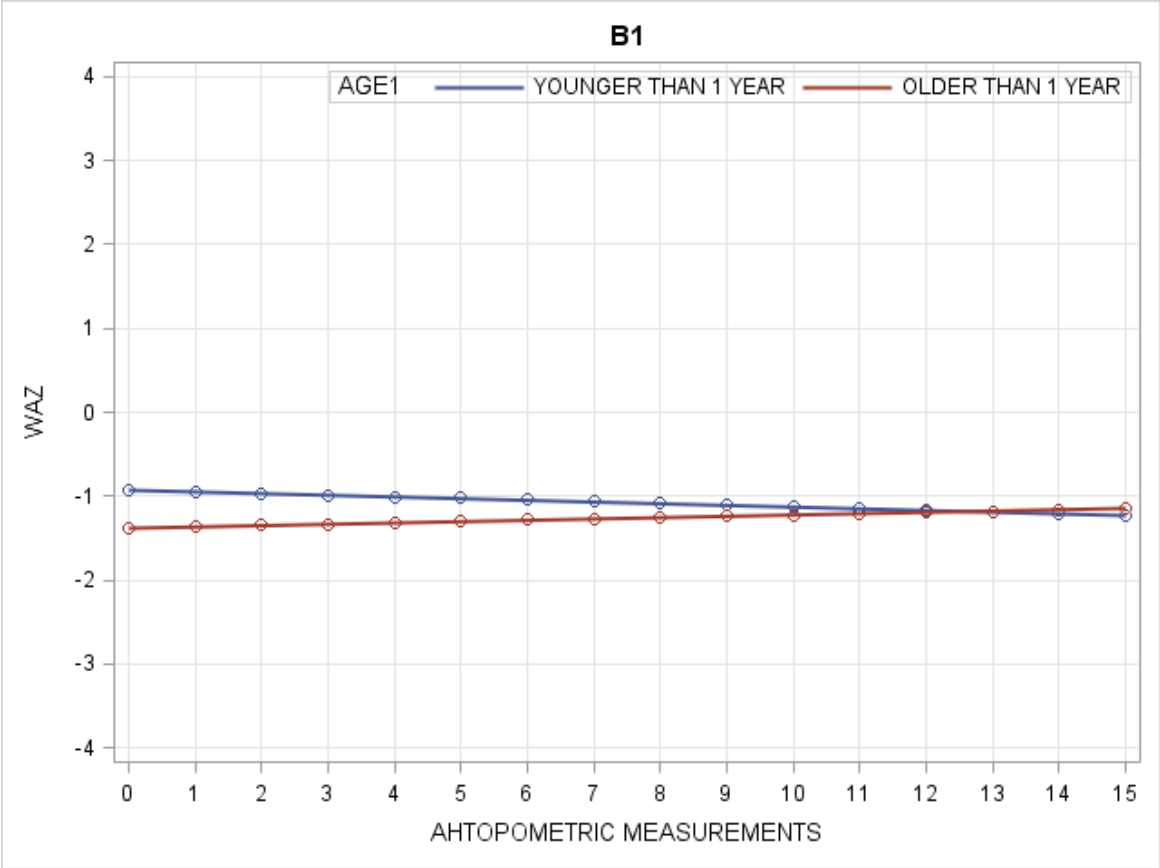

Figure 4 Result of fitted WAZ trajectories for Model C

Discussion:

The prevalences of stunting and wasting in our study were 26.9% and 25.4%, respectively. Compared with other studies conducted in Cambodia, the prevalence of stunting in our study is similar to their results, however the prevalence of wasting is much higher than other studies.(47) The prevalences of wasting among children under five years has been evidenced varying across different provinces of Cambodia.(48) Considering that our GMP was conducted in a rural village of one of the poorest provinces in Cambodia, the higher prevalence of wasting in our study might be due to geographic developmental disparity.

The initial HAZ in the group under 1 year was higher than the group above 1 year in our study. This finding is compatible with a unique HAZ and WAZ trajectory patterns among children from birth to 36 months in developing countries. In developing countries, the HAZ is highest at birth and then declines continuously until it reaches a nadir around 24-36 months.(27) However, instead of continuously declining from birth, the WAZ fluctuates in the first 36 months of life. The initial higher WAZ in our younger group might not have significant implications as the WAZ is volatile in the first 36 months of life.

The HAZ growth trajectories in our two groups, under 1 year and between 1 and 2 years, differed from the usual HAZ pattern observed in developing countries. Instead of declining from birth until 24-36 months, the two groups turned around their declining HAZ trajectories at the second anthropometric measurement. Their nadirs of HAZ trajectories in our study came faster than it was expected. As for the oldest age group above 2 years, the slope was relatively flat at the same HAZ level. At the end of our program, the final HAZ values were no different among the three groups.

The WAZ growth trajectories of our 3 groups had similar patterns: the curves did not decline but fluctuated slightly. This is compatible with observations of WAZ trends in developing countries.

We speculate that our GMP might avert the downward trend of HAZ in the younger group substantially. A study corroborated our argument that a child who has a stable HAZ in the first two years of life would be considered better than average, and a child older than two years who has a stable HAZ is the expected pattern.(49) Among the three groups, our program was more effective among children under 2 years as we averted the downward HAZ slopes in the two younger groups, but we did not elevate the slope of HAZ

trajectory among children above 2 years. Growth faltering in the first 1000 days of life causes irreversible short-term and long-term consequences.(1) Based on our result, we should implement an effective GMP at an age earlier than 2 years old, as children will have the most benefits. Physical and neurological consequences caused by undernutrition during this critical period can be prevented.

In a longitudinal data set, the number of waves and the spacing are crucial elements for detecting outcome changes. Optimizing spacing between anthropometric measurements is a challenge for linear growth monitoring in developing countries. If the interval between two measurements is too short, the effect of measurement errors will not be minimalized. If the interval is too long, we might miss capturing characteristics of fast changing trajectories.(49) The optimal interval for children under 12 months is 3-4 months and 6 months for children older than 12 months.(49) Therefore, we designed 16 waves of anthropometric measurement with a spacing of 3 months across a 4-year period in our GMP. Ample waves and a narrow spacing can facilitate an elaborate statistical model.

Before we proceed to model-based analysis, exploratory graphical analyses provide preliminary characteristics of our data. There are two ways to conduct graphical analyses: nonparametric and parametric. The advantage of nonparametric approach is that it does not require assumptions and can capture temporal change of interests. Nonparametric graphic analysis also hints us a possible functional form for next stage of parametric analysis.(50) Taking our case for example, the two groups of younger children had a downward curve spanning only 3-6 months. If we presumably specified our growth model as a parametric model first, we would not be able to capture these downward HAZ segments. However, a nonparametric model only provides visual conclusions without meaningful parameters. After the visual analysis, a parametric model is needed for making a generalization.

Our data is a longitudinal growth curve investigating growth change over time. In this case, a cross-sectional approach is not suitable to address our research question. A multilevel growth modeling (linear mixed-effects modeling) can provide parameters for specifying a statistical model for change.(51) In a multilevel growth analysis, we must posit level-1 within-person and level-2 between-person model first. All the following models processed are based on the initial level-1/level-2 model. Taxonomy of multilevel

models is an approach with several models to address research question. Before we proceed to fit a full multilevel growth model, we should specify two preliminary models first: (1) an unconditional means model (model A) and (2) an unconditional growth model (model B).(51) These two unconditional models provide quantitative information where the variation resides (within or between people) and the statistical benchmark for comparison with subsequent models. Taking the HAZ trajectory for example, the three parameters, Υ_{00}, σ^2_{ε}, and σ^2_0 in model A were all significantly different from zero. The non-zero σ^2_{ε} and σ^2_0 implied that the within-person HAZ variations changed over time and the HAZ changes differs from each other among our participants. The intraclass correlation coefficient ρ being 0.78 implied that 78% of total HAZ variation was attributable to differences among our children. Model B was derived from model A by incorporating "WAVE" into the model A. Model B was aimed to verify that the HAZ of each child changed across different anthropometric measurements. The result of Model B revealed that the initial status and slope of HAZ trajectories were not zero. Furthermore, the σ^2_{ε} decreased from 0.33 in model A to 0.17 in model B. The decrease of σ^2_{ε} meant the model B explained more variability of individual's HAZ change than the model A. The extent of σ^2_{ε} decrease showed that 48% of within-person variation in HAZ was systemically associated with linear WAVE. Based on the results of model A and B, we added level-2 predictors in model C to explain more variability of HAZ change. In model C, our research predictor AGE2 was incorporated into the model B. In model D we further added FOLLOWPERIOD as a control predictor into model C. The results from model C and D revealed that the initial status and slopes of HAZ differed between children younger and older than 1 year old. And the length of follow-up in our program also influenced the slope of WAZ and HAZ.

With the aim to address undernutrition issues in Africa, growth monitoring (GM) emerged in the 1960s. (52) However, original stand-alone GMs with regular measurements of weight and height have little impact on improving child undernutrition. Eventually, follow-up interventions were incorporated into the original GM to transform it into a growth monitoring and promotion (GMP). In practice, the range of interventions put in place in a GMP is tailored to the context of different communities. Ideally, the extent of interventions implemented in a GMP should fit the needs of local communities. However, financial resources and local

public health infrastructure also limit the scale of interventions. Usually, a GMP encompasses a bundle of interventions and so it is difficult to decide which elements of a GMP will ensure a favorable outcome. From the literature review, we noticed that the outcome of a GMP depends on a variety of factors. We tried to deliver a comprehensive and sustainable GMP based on past successful and failed GMPs. First, we enrolled a target population ranging from 6 months to 5 years old. We tried to recruit children under 2 years old as this age range is critical for child development. As we did not have a control group in our GMP, we stratified our study population into two groups: under 2 years and above 2 years old. The comparison of the two age groups constituted the backbone of our study. The results of our study also answered our research question in that we modified the typical HAZ trajectory of children under 1 year observed in developing countries in this community.

We could not find publications investigating whether the length of GMP duration has impacts on its success. The duration of most GMPs usually ranged from 6 months to 2 years. We purposely lengthened our program to 4 years. In our study, three groups of children entered our GMP at different time points. Based on the result of model D, the longer the child stayed in our program, the greater improvement of HAZ was noticed. We did not find that the length of follow-up in this program had any impact on WAZ trajectory. However, HAZ is a more sensitive indicator for chronic undernutrition than WAZ. We believe that a longer period of GMP might have a greater impact on child undernutrition in developing countries.

Workforce capacity influences the efficacy of a GMP delivery directly. A workforce mixed with paid, trained workers and community volunteers has a synergistic effect in delivering GMP interventions.(53, 54) A trained worker can deliver in-depth nutrition counseling and accurate anthropometric measurements. Local volunteers can help cultivate connections between community workers and local families. Optimization of workload is another issue that influences the efficacy of a GMP. In our GMP, less than 100 children were assigned to each community worker. A realistic ratio between workers and families guarantees the quality of nutritional counseling during home visits. Besides, a full-time pediatrician provided supportive supervision for our community workers and helped resolve challenges community workers faced during home visits. The supportive supervision of community-level workers from the next level of healthcare

worker ensured the consistency of intervention delivery.

The effectiveness of GMP was also weakened by some other factors. Lack of participation of caregivers, poor understanding of the concept of growth monitoring, and poor community involvement were those mentioned in past studies.(55) To overcome barriers that deter caregivers from our services, the venues of our anthropometric measurements and nutrition education sessions were in proximity to caregivers' residences within a small group setting. The format of a small group facilitated bi-directional communication between community workers and caregivers. It also cultivated a positive deviance effect for the caregivers. A positive deviance approach has been effective in community programs.(56)

Community-based monitoring without home visits had limited impact on child nutrition. (57) Home visits were the foundation of our GMP which served as a platform of interventions. We operated a variety of follow-up actions via home visits. In general, GMP is unlikely to succeed if mothers lack awareness of proper child-feeding practices, and if they are not supported by other family members.(58) Home visits can grow consensus among family members. The education level of the mother is also a key factor for the promotion of child health. Many studies have shown how the education status of mother influenced the effectiveness of a GMP.(59) In this region, we found that many caregivers were grandparents. Hence, individual tailored nutrition counseling can compensate for the knowledge gap of caregivers.

At the community level, we had a partnership with local stakeholders with a monthly meeting. Local stakeholders were involved in the process of shaping policies implementation. Coordination with local stakeholders can assist policy design in the early phase and tailor to the needs of local communities.

The limitation our study existed in some respects. There are some limitations to this study. First, our study was a small scale GMP with only 368 children geographically limited to a single village. Our experience might not be replicable in other contexts. Besides, not all guardians were willing to enter this GMP and this might result in selection bias as parent who entered this program might be more motivated to change their behavior for nutrition improvement of their children. Secondly, children entered this GMP at different ages and therefore they were at different phases of their growth trajectories. We only divided our children into 3 age groups and the age range was 12 months in each group. In a range of 12 months especially in the

group of under 12 months, HAZ of children who had reach nadirs of their growth curves was starting to climb while HAZ of some children might still on the path of declining. Due to the heterogeneity of growth curves, the average HAZ trajectories might not be representative of the whole group.

In the future, we recommend that we should divide our children into groups with a narrow age range to avoid heterogeneity of growth curves. We also should quantify behavior change of caregivers to establish a stronger causal relationship between our program efforts, behavior change of caregivers, and nutrition improvement of children.

Our conclusion is that an effective GMP needs a bidirectional and frequent dialogue between caregivers and community workers. The dialogue should be tailored to the needs of local communities at both individual household and community levels. A longer GMP benefits child undernutrition more than a shorter one.

References

1. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1659-724.
2. Bagriansky J, Champa N, Pak K, Whitney S, Laillou A. The economic consequences of malnutrition in Cambodia, more than 400 million US dollar lost annually. Asia Pacific journal of clinical nutrition. 2014;23(4):524-31.
3. Lomborg B. Global crises, global solutions: Cambridge university press; 2004.
4. McDonald CM, Olofin I, Flaxman S, Fawzi WW, Spiegelman D, Caulfield LE, et al. The effect of multiple anthropometric deficits on child mortality: meta-analysis of individual data in 10 prospective studies from developing countries. Am J Clin Nutr. 2013;97(4):896-901.
5. Victora CG, Adair L, Fall C, Hallal PC, Martorell R, Richter L, et al. Maternal and child undernutrition: consequences for adult health and human capital. Lancet. 2008;371(9609):340-57.
6. Van Beekum M, Berger J, Van Geystelen J, Hondru G, Som SV, Theary C, et al. The associations between stunting and wasting at 12 months of age and developmental milestones delays in a cohort of Cambodian children. Sci Rep. 2022;12(1):17859.
7. UNICEF Data: Monitoring the Situation of Children and Women: UNICEF; 2023 [Available from: https://data.unicef.org/topic/child-survival/under-five-mortality/.
8. Dukhi N. Global prevalence of malnutrition: evidence from literature. Malnutrition. 2020;1:1-16.
9. Organization WH. World Health Organization. Malnutrition Key Facts. 2018. p. 1-7.
10. McCoy DC, Peet ED, Ezzati M, Danaei G, Black MM, Sudfeld CR, et al. Early Childhood Developmental Status in Low- and Middle-Income Countries: National, Regional, and Global Prevalence Estimates Using Predictive Modeling. PLoS Med. 2016;13(6):e1002034.
11. Matanda DJ, Mittelmark MB, Kigaru DMD. Child undernutrition in Kenya: trend analyses from 1993 to 2008–09. BMC pediatrics. 2014;14:1-13.
12. Pasricha SR, Biggs BA. Undernutrition among children in south and south-east Asia. Journal of paediatrics and child health. 2010;46(9):497-503.
13. Nandy S, Irving M, Gordon D, Subramanian S, Smith GD. Poverty, child undernutrition and morbidity: new evidence from India. Bulletin of the World Health Organization. 2005;83:210-6.
14. Garrett J, Ruel MT. The coexistence of child undernutrition and maternal overweight: prevalence, hypotheses, and programme and policy implications. Maternal & child nutrition. 2005;1(3):185-96.
15. UNICEF. WHO, International Bank for Reconstruction and Development/The World Bank. Levels and trends in child malnutrition: Key findings of the 2021 edition of the joint child malnutrition estimates. Geneva: WHO. 2021.
16. D. M. Pediatric Priorties in the Developing World. London: Butterworths; 1973.
17. WHO Guidelines Approved by the Guidelines Review Committee. Guideline: Assessing and Managing Children at Primary Health-Care Facilities to Prevent Overweight and Obesity in the Context of the Double Burden of Malnutrition: Updates for the Integrated Management of Childhood Illness (IMCI). Geneva: World Health Organization
Copyright © World Health Organization 2017.; 2017.
18. Ashworth A, Shrimpton R, Jamil K. Growth monitoring and promotion: review of evidence of impact. Matern Child Nutr. 2008;4 Suppl 1(Suppl 1):86-117.

19. Gerein NM, Ross DA. Is growth monitoring worthwhile? An evaluation of its use in three child health programmes in Zaire. Soc Sci Med. 1991;32(6):667-75.
20. Teklemuz N, Sisay M, Baffa LD, Mengistu B, Atenafu A. Utilization of growth monitoring and promotion services among children younger than 2 years in West Armachiho district, Northwest Ethiopia. Front Public Health. 2023;11:1179720.
21. George SM, Latham MC, Abel R, Ethirajan N, Frongillo EA, Jr. Evaluation of effectiveness of good growth monitoring in south Indian villages. Lancet. 1993;342(8867):348-52.
22. Fahmida U, Htet MK, Ferguson E, Do TT, Buanasita A, Titaley C, et al. Effect of an Integrated Package of Nutrition Behavior Change Interventions on Infant and Young Child Feeding Practices and Child Growth from Birth to 18 Months: Cohort Evaluation of the Baduta Cluster Randomized Controlled Trial in East Java, Indonesia. Nutrients. 2020;12(12).
23. Stein AD, Wang M, Martorell R, Norris SA, Adair LS, Bas I, et al. Growth patterns in early childhood and final attained stature: data from five birth cohorts from low- and middle-income countries. Am J Hum Biol. 2010;22(3):353-9.
24. Stein AD, Wang M, Martorell R, Norris SA, Adair LS, Bas I, et al. Growth patterns in early childhood and final attained stature: data from five birth cohorts from low-and middle-income countries. American Journal of Human Biology. 2010;22(3):353-9.
25. Kuklina EV, Ramakrishnan U, Stein AD, Barnhart HH, Martorell R. Early childhood growth and development in rural Guatemala. Early human development. 2006;82(7):425-33.
26. Albelbeisi A, Shariff ZM, Mun CY, Abdul-Rahman H, Abed Y. Growth patterns of Palestinian children from birth to 24 months. Eastern Mediterranean Health Journal. 2018;24(3).
27. Costa JC, Blumenberg C, Victora C. Growth patterns by sex and age among under-5 children from 87 low-income and middle-income countries. BMJ Global Health. 2021;6(11):e007152.
28. Hondru G, Laillou A, Wieringa FT, Poirot E, Berger J, Christensen DL, et al. Age-appropriate feeding practices in cambodia and the possible influence on the growth of the children: A longitudinal study. Nutrients. 2019;12(1):12.
29. Hondru G, Wieringa FT, Poirot E, Berger J, Som SV, Theary C, et al. The interaction between morbidity and nutritional status among children under five years old in Cambodia: A longitudinal study. Nutrients. 2019;11(7):1527.
30. Lourenço BH, Villamor E, Augusto RA, Cardoso MA. Determinants of linear growth from infancy to school-aged years: a population-based follow-up study in urban Amazonian children. BMC public health. 2012;12:1-11.
31. Lundeen EA, Stein AD, Adair LS, Behrman JR, Bhargava SK, Dearden KA, et al. Height-for-age z scores increase despite increasing height deficits among children in 5 developing countries. The American journal of clinical nutrition. 2014;100(3):821-5.
32. Greffeuille V, Sophonneary P, Laillou A, Gauthier L, Hong R, Hong R, et al. Persistent inequalities in child undernutrition in Cambodia from 2000 until today. Nutrients. 2016;8(5):297.
33. Chhoun P, Pal K, Oy S, Collins C, Tuot S, Yi S. Social determinants of maternal and child undernutrition in Cambodia: A systematic review. International Journal of Food and Nutritional Science. 2016;3(2):331.
34. McDonald CM, McLean J, Kroeun H, Talukder A, Lynd LD, Green TJ. Household food insecurity and dietary diversity as correlates of maternal and child undernutrition in rural Cambodia. European Journal of Clinical Nutrition. 2015;69(2):242-6.

35. Nakphong MK, Beltrán-Sánchez H. Socio-economic status and the double burden of malnutrition in Cambodia between 2000 and 2014: overweight mothers and stunted children. Public Health Nutrition. 2021;24(7):1806-17.
36. Kubota Y, Pech NS, Durward C, Ogawa H. Underweight and early childhood caries among young children in rural Cambodia: a pilot study. BDJ open. 2021;7(1):33.
37. Laillou A, Gauthier L, Wieringa F, Berger J, Chea S, Poirot E. Reducing malnutrition in Cambodia. A modeling exercise to prioritize multisectoral interventions. Maternal & Child Nutrition. 2020;16:e12770.
38. Caron Y, Hong R, Gauthier L, Laillou A, Wieringa FT, Berger J, et al. Stunting, beyond acute diarrhoea: Giardia duodenalis, in Cambodia. Nutrients. 2018;10(10):1420.
39. Manzoni G, Laillou A, Samnang C, Hong R, Wieringa FT, Berger J, et al. Child-sensitive WASH composite score and the nutritional status in Cambodian children. Nutrients. 2019;11(9):2142.
40. Menasria L, Blaney S, Main B, Vong L, Hun V, Raminashvili D, et al. Mitigated Impact of Provision of Local Foods Combined with Nutrition Education and Counseling on Young Child Nutritional Status in Cambodia. Nutrients. 2018;10(10).
41. Mutunga M, Rutishauser-Perera A, Laillou A, Prak S, Berger J, Wieringa FT, et al. The relationship between wasting and stunting in Cambodian children: Secondary analysis of longitudinal data of children below 24 months of age followed up until the age of 59 months. PloS one. 2021;16(11):e0259765.
42. Johnson W. Analytical strategies in human growth research. Am J Hum Biol. 2015;27(1):69-83.
43. Fine KL, Suk HW, Grimm KJ. An Examination of a Functional Mixed-Effects Modeling Approach to the Analysis of Longitudinal Data. Multivariate Behav Res. 2019;54(4):475-91.
44. Grajeda LM, Ivanescu A, Saito M, Crainiceanu C, Jaganath D, Gilman RH, et al. Modelling subject-specific childhood growth using linear mixed-effect models with cubic regression splines. Emerg Themes Epidemiol. 2016;13:1.
45. Johnson W, Balakrishna N, Griffiths PL. Modeling physical growth using mixed effects models. Am J Phys Anthropol. 2013;150(1):58-67.
46. Murphy JI, Weaver NE, Hendricks AE. Accessible analysis of longitudinal data with linear mixed effects models. Dis Model Mech. 2022;15(5).
47. Som SV, Van Der Hoeven M, Laillou A, Poirot E, Chan T, Polman K, et al. Adherence to child feeding practices and child growth: A retrospective cohort analysis in cambodia. Nutrients. 2020;13(1):137.
48. Van Beekum M, Berger J, Van Geystelen J, Hondru G, Som SV, Theary C, et al. The associations between stunting and wasting at 12 months of age and developmental milestones delays in a cohort of Cambodian children. Scientific Reports. 2022;12(1):17859.
49. Wit JM, Himes JH, van Buuren S, Denno DM, Suchdev PS. Practical Application of Linear Growth Measurements in Clinical Research in Low- and Middle-Income Countries. Horm Res Paediatr. 2017;88(1):79-90.
50. Fitzmaurice GM, Davidian, M., Verbeke, G., &, Molenberghs GE. Longitudinal Data Analysis. Boca Raton, FL: CRC Press/Taylor & Francis; 2009.
51. D. SJ, B. WJ. Applied longitudinal data analysis: Modeling change and event occurrence. Illustrated ed. USA: Oxford University Press; 2003. 644 p.
52. Morley D, Knox G. The birth weights of Yoruba babies. 1960.

53. Scott K, Beckham SW, Gross M, Pariyo G, Rao KD, Cometto G, et al. What do we know about community-based health worker programs? A systematic review of existing reviews on community health workers. Hum Resour Health. 2018;16(1):39.
54. Tomlinson M, Sherr L, Macedo A, Hunt X, Skeen S. Paid staff or volunteers - does it make a difference? The impact of staffing on child outcomes for children attending community-based programmes in South Africa and Malawi. Glob Health Action. 2017;10(1):1381462.
55. Charlton KE, Kawana BM, Hendricks MK. An assessment of the effectiveness of growth monitoring and promotion practices in the Lusaka district of Zambia. Nutrition. 2009;25(10):1035-46.
56. Chek LP, Gan WY, Chin YS, Sulaiman N. A nutrition programme using positive deviance approach to reduce undernutrition among urban poor children under-five in Malaysia: A cluster randomised controlled trial protocol. PLoS One. 2022;17(10):e0275357.
57. Fink G, Levenson R, Tembo S, Rockers PC. Home-and community-based growth monitoring to reduce early life growth faltering: an open-label, cluster-randomized controlled trial. The American journal of clinical nutrition. 2017;106(4):1070-7.
58. Bilal SM, Moser A, Blanco R, Spigt M, Dinant GJ. Practices and challenges of growth monitoring and promotion in ethiopia: a qualitative study. J Health Popul Nutr. 2014;32(3):441-51.
59. Nguyen HT, Eriksson B, Petzold M, Bondjers G, Tran TK, Nguyen LT, et al. Factors associated with physical growth of children during the first two years of life in rural and urban areas of Vietnam. BMC Pediatr. 2013;13:149.

Table 1. Baseline Characteristics of Children With Initial and Final Anthropometric information, Cambodia, 2016-2019

	Whole group (N=358)	**Age < 12 months (N=136)**	**Age ≥ 12 months (N=222)**	
Characteristics				*P* value
Average age (months, mean ± SD)	17.22 ± 10.39	10.39 ± 6.54	30.32 ± 4.96	
Male (n [%])	187 (52.2)	70 (51.5)	117 (52.7)	0.83
Average period of follow-up (months, mean ± SD)	25.57 ± 5.20	23.81 ± 5.40	26.64 ± 4.78	<0.01
Enrolled at the start of GMP	168 (46.9)	45 (33.1)	123 (55.4)	<0.01
HAZ				
Enrolment (mean ± SD)	-1.32 ± 1.32	-0.98 ± 1.48	-1.53± 1.17	<0.01
Endpoint (mean ± SD)	-1.18 ± 0.91	-1.09 ± 1.00	-1.24 ± 0.84	0.14
WAZ				
Enrolment (mean ± SD)	-1.21 ± 1.22	-0.86 ± 1.34	-1.44 ± 1.10	<0.01
Endpoint (mean ± SD)	-1.15 ± 0.93	-1.06 ± 1.04	-1.21 ± 0.86	0.19
Stunting				
Enrolment (n [%])	90 (26.9)	25 (19.2)	65 (31.7)	0.02
Endpoint (n [%])	46 (19.09)	25 (19.0)	37 (18.1)	0.89
Wasting				
Enrolment (n [%])	88 (25.4)	23 (17.2)	65 (30.5)	<0.01
Endpoint (n [%])	170 (47.5)	27 (19.6)	56 (25.2)	0.30

SD: Standard deviation

Table 2. Demographic Characteristics for children And Two Age Groups, Cambodia, 2016-2019

	Whole group (N=358)	**Age < 12 months (N=136)**	**Age > 12 months (N=222)**	
Characteristics				*P* value
Number of siblings (mean ± SD)	0.82 ± 1.09	0.79 ± 0.98	0.84 ± 1.15	0.64
Main caregiver (Parents, n [%])	192 (54.9)	80 (61.1)	112 (51.1)	0.08
IDPoor (n [%])	69 (19.3)	22 (16.2)	47 (21.2)	0.27
Vitamin A supplement (n [%])	206 (57.5)	59 (43.4)	147 (66.2)	<0.01
De-worming (n [%])	141 (40.4)	24 (18.5)	117 (53.4)	<0.01
Vaccination conformity (n [%])	247 (70.8)	79 (60.8)	168 (76.7)	<0.01
Mother's education				0.21
High school completion	132 (37.7)	55 (42.0)	77 (35.2)	
No high school diploma	218 (62.3)	76 (58.0)	142 (64.8)	
Expense on food each day				<0.01
<$2.5 (n [%])	87 (24.9)	42 (32.1)	45 (20.6)	
$2.5-$5 (n [%])	205 (58.6)	76 (58.0)	129 (58.9)	
>$5 (n [%])	58 (16.6)	13 (9.9)	45 (20.6)	
Food preparation				<0.01
Mother	147(42.0)	119(48.0)	28 (27.4)	
Grandparents	178(50.9)	115(46.4)	63(61.8)	
Others	25(7.1)	14(5.7)	11(10.8)	
Water sources				0.054
Tap water	139(39.7)	61(46.6)	78(35.6)	
Others (well/rain/fresh) water	211(60.3)	70(53.4)	141(64.4)	
Boiling water before drinking				0.02
Yes	220 (63.2)	92 (71.3)	128 (58.5)	
No	128 (36.8)	37 (28.7)	91 (41.6)	

Table 3. Results of fitting a taxonomy of multilevel models for change to the WAZ data (n = 358)

		Parameter	Model A	Model B	Model C	Model D
Fixed Effects						
Initial status, π_{0i}	Intercept	Υ_{00}	-1.19	-1.20	-0.92	-0.87
		(SE)	(0.05)	(0.05)	(0.09)	(0.09)
	AGE2	Υ_{01}			-0.45	-0.41
		(SE)			(0.11)	(0.11)
	FOLLOW PERIOD	Υ_{02}				-0.17
		(SE)				(0.11)
Rate of change, π_{1i}	Intercept	Υ_{10}		0.002	-0.02	-0.02
		(SE)		(0.004)	(0.008)	(0.007)
	AGE2	Υ_{11}			0.04	0.03
		(SE)			(0.01)	(0.01)
	FOLLOW PERIOD	Υ_{12}				0.005
		(SE)				(0.01)
Variance components						
Level 1	Within-person	σ^2_{ε}	0.21	0.12	0.12	0.12
		(SE)	(0.005)	(0.003)	(0.003)	(0.003)
Level 2	In initial status	σ^2_0	0.76	1.00	0.96	0.95
		(SE)	(0.06)	(0.08)	(0.08)	(0.08)
	In rate of change	σ^2_1		0.007	0.007	0.007
		(SE)		(0.0005)	(0.0006)	(0.0006)
	Covariance	σ^2_{01}		-0.04	-0.04	-0.04
		(SE)		(0.005)	(0.006)	(0.005)
Pseudo R^2 statistics and Goodness-of-fit						
R^2_{YY}			0.004	0.01	0.02	
R_{ε}^2			0.43	0.43	0.43	
R_0^2				0.04	0.02	
R_1^2				0.00	0.00	
Deviance			6096.8	4918.5	4898.6	4896.1
AIC			6102.8	4930.5	4914.6	4916.1
BIC			6114.4	4953.8	4945.6	4954.9

SE: Standard error

AGE: dichotomic predictor between age 2yrs.

FOLLOWPERIOD: dichotomic predictor for participants enrolled in the start of the GMP or not.

WAVE: anthropometric measurements.

Table 4. Results of fitting a taxonomy of multilevel models for change to the HAZ data (n = 358)

		Parameter	Model A	Model B	Model C	Model D
Fixed Effects						
Initial status, π_{0i}	Intercept	Υ_{00}	-1.27	-1.37	-1.08	-0.89
		(SE)	(0.05)	(0.06)	(0.10)	(0.10)
	AGE2	Υ_{01}			-0.46	-0.33
		(SE)			(0.13)	(0.13)
	FOLLOW PERIOD	Υ_{02}				-0.56
		(SE)				(0.13)
Rate of change, π_{1i}	Intercept	Υ_{10}		0.01	-0.006	-0.02
		(SE)		(0.005)	(0.008)	(0.009)
	AGE2	Υ_{11}			0.03	0.02
		(SE)			(0.01)	(0.01)
	FOLLOW PERIOD	Υ_{12}				0.04
		(SE)				(0.01)
Variance components						
Level 1	Within-person	σ^2_{ε}	0.33	0.17	0.17	0.17
		(SE)	(0.008)	(0.004)	(0.005)	(0.005)
Level 2	In initial status	σ^2_0	0.80	1.38	1.34	1.26
		(SE)	(0.06)	(0.10)	(0.10)	(0.10)
	In rate of change	σ^2_1		0.008	0.008	0.008
		(SE)		(0.0007)	(0.0007)	(0.0007)
	Covariance	σ^2_{01}		-0.07	-0.07	-0.06
		(SE)		(0.008)	(0.007)	(0.008)
Pseudo R^2 statistics and Goodness-of-fit						
R^2_{YY}				0.008	0.02	0.06
R_{ε}^2				0.48	0.48	0.48
R_0^2					0.00	0.09
R_1^2					0.00	0.00
Deviance			7608.9	6268.0	6254.6	6234.1
AIC			7614.9	6280.0	6044.6	6254.1.7
BIC			7626.5	6303.3	6075.6	6292.9

SE: Standard error

AGE: dichotomic predictor between age 2yrs.

FOLLOWPERIOD: dichotomic predictor for participants enrolled in the start of the GMP or not.

WAVE: anthropometric measurements.

Table 5. Taxonomy of multilevel models for change fitted to the WAZ and HAZ data.

	Level 1/Level 2 specification		
Model	Level-1 model	Level-2 model	Composite model
A	$Y_{ij} = \pi_{0i} + \varepsilon_{ij}$	$\pi_{0i} = \gamma_{00} + \zeta_{0i}$	$Y_{ij} = \pi_{0i} + [\gamma_{00} + \zeta_{0i}]$
B	$Y_{ij} = \pi_{0i} + \pi_{1i}WAVE_{ij} + + \varepsilon_{ij}$	$\pi_{0i} = \Upsilon_{00} + \zeta_{0i}$ $\pi_{1i} = \Upsilon_{10} + \zeta_{1i}$	$Y_{ij} = \Upsilon_{00} + \Upsilon_{10}WAVE_{ij} + [\zeta_{0i} + \zeta_{1i}WAVE_{ij} + \varepsilon_{ij}]$
C	$Y_{ij} = \pi_{0i} + \pi_{1i}WAVE_{ij} + + \varepsilon_{ij}$	$\pi_{0i} = \Upsilon_{00} + \Upsilon_{01}AGE2_i + \zeta_{0i}$ $\pi_{1i} = \Upsilon_{10} + \Upsilon_{11}AGE_i + \zeta_{1i}$	$Y_{ij} = \Upsilon_{00} + \Upsilon_{01}AGE1_i + \Upsilon_{10}WAVE_{ij} + \Upsilon_{11}AGE1_i\ WAVE_{ij} + [\zeta_{0i} + \zeta_{1i}WAVE_{ij} + \varepsilon_{ij}]$
D	$Y_{ij} = \pi_{0i} + \pi_{1i}WAVE_{ij} + + \varepsilon_{ij}$	$\pi_{0i} = \Upsilon_{00} + \Upsilon_{01}AGE1_i + \Upsilon_{02}FOL-LOWPERIOD_i + \zeta_{0i}$ $\pi_{1i} = \Upsilon_{10} + \Upsilon_{11}AGE1_i + \Upsilon_{12}FOL-LOWPERIOD_i + \zeta_{1i}$	$Y_{ij} = \Upsilon_{00} + \Upsilon_{01}AGE1_i + \Upsilon_{02}FOL-LOWPERIOD_i + \Upsilon_{10}WAVE_{ij} + \Upsilon_{11}AGE1_i\ WAVE_{ij} + \Upsilon_{12}FOL-LOWPERIOD_i\ WAVE_{ij} + [\zeta_{0i} + \zeta_{1i}WAVE_{ij} + \varepsilon_{ij}]$

AGE is a dichotomic predictor between age 2 yrs.
FOLLOWPERIOD is a dichotomic predictor for participants enrolled in the start of the GMP or not.
WAVE indicates anthropometric measurements.