Ann. N.Y. Acad. Sci. ISSN 0077-8923

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Special Issue: *Adolescent Nutrition*
ORIGINAL ARTICLE

Transitions to adulthood and the changing body mass index of adolescent girls in Zambia

Erica Soler-Hampejsek,[1] Paul C. Hewett,[2] Kathryn Spielman,[2] and Karen Austrian[3]

[1]Independent Consultant, Barcelona, Spain. [2]Population Council, Washington, DC. [3]Population Council, Nairobi, Kenya

Address for correspondence: Paul C. Hewett, Population Council, 4301 Connecticut Ave NW # 280, Washington, DC 20008. phewett@popcouncil.org

Adolescent girls in low- and middle-income countries often experience several important life transitions, including school-leaving, marriage, and childbearing. Understanding how these transitions are associated with changes in the nutritional status of adolescent girls and young women (AGYW) is crucial for programs that aim to improve nutritional outcomes among youth and promote healthy transitions to adulthood. We investigated the associations between adolescent transitions and body mass index (BMI) among a cohort of 4887 adolescent girls in Zambia aged 10–19 years when first interviewed in 2013. Estimating fixed-effects models controlling for constant and time-varying confounders, we found that school-leaving, marital status, and childbearing are associated with the nutritional status of AGYW in diverse ways. School-leaving was associated with higher BMI and increased odds of overweight/obesity. Marriage was not only associated with increased odds of undernutrition, particularly in rural areas, but also with increased odds of overweight/obesity among older girls. Motherhood was associated with lower BMI and lower odds of overweight/obesity, particularly among breastfeeding mothers. Our results provide evidence of characteristics of AGYW that would be useful for targeted nutritional interventions and behavior change programming, including girls leaving school, recently married, and young women undergoing a marital separation, as well as young mothers and their children.

Keywords: adolescents; body mass index; schooling; marriage; Zambia

Introduction

Adolescence is a critical transitional period in the lives of young girls in terms of their physical, cognitive, and emotional development. In low- and middle-income countries, adolescence is also a period when young girls may begin childbearing. Nutrition is increasingly recognized as a critical ingredient to maternal and child health, and child growth and cognitive development. Undernutrition is associated with higher risk of adverse pregnancy outcomes, including preterm birth and low birth weight, as well as increased mortality risk during childbirth.[1–3] Undernutrition can also have a direct impact on the immune function of adolescents and increase their susceptibility to infectious diseases.[4,5] Despite progress in recent decades, undernutrition has persisted in sub-Saharan African countries, at the same time that the region has been experiencing a rise in the prevalence of overweight and obesity, which have lifetime consequences.[6–8]

Understanding how major life transitions (school-leaving, marriage, and childbearing) change the nutritional status of adolescent girls and young women (AGYW) is crucial for programs and policies that aim to improve nutritional outcomes and promote healthy transitions to adulthood. The objective of this paper is to fill evidence gaps needed to improve nutritional outcomes among adolescents. To do so, this paper will address the following research questions: (1) Are school-leaving and marriage associated with higher body mass index (BMI) and higher likelihood of being overweight and obese? (2) Is childbearing associated with lower BMI and higher likelihood of being underweight? and (3) Are the associations between key adolescent transitions and BMI explained by work,

doi: 10.1111/nyas.14291

time spent doing household chores, and household wealth?

Background

In Zambia, between adolescence (aged 15–19 years) and young adulthood (aged 20–29 years), the prevalence of undernutrition among girls drops in half from 16.4% to 8.5%, while the prevalence of overweight and obesity more than quadruples from 1.1% to 4.8%.[9] Alongside substantial changes in nutritional status, AGYW in Zambia often leave school, marry, and begin childbearing within a short period of time. Female school attendance rates decline steeply during late adolescence, from around 85% at age 15 to less than 25% at age 19; while the prevalence of ever given birth increases from 23% among adolescent girls aged 15–19 years to 74% among young women aged 20–24 years, followed closely by the prevalence of ever been married, which increases from 19% among adolescent girls aged 15–19 years to 64% among young women aged 20–24 years.[9]

The large majority of school girls in places like Zambia walk to and from school, which has been associated with lower likelihood of overweight and obesity among school children in Tanzania,[10] and young adults in Uganda.[11] School-leaving is often driven by, or closely followed by, marriage.[12,13] Studies from high-income countries have found that nutritional status, reflected by physical attributes and health behaviors, is significantly associated with the likelihood of marriage.[14] Being underweight can be perceived not only as not yet being physically mature but also as not having good health, particularly in contexts where HIV prevalence is high,[15] as is the case in Zambia. Studies reviewing the literature on marital transitions and BMI found that transitions into marriage are associated with higher BMI in the United States, other developed countries, and in Mexico, and that married adults are more likely to be overweight and obese.[16–18] Finally, in Zambia, breastfeeding is nearly universal during children's first year of life and is common during their second year of life,[9] and has been associated with lower BMI among adult women in other African settings.[19,20]

Materials and methods

Data

We used data from four rounds of a longitudinal survey of adolescent girls that was conducted to evaluate the impact of the Adolescent Girls Empowerment Program (AGEP) in Zambia. AGEP was a multisectoral asset-building program for vulnerable adolescent girls with a cluster-randomized controlled trial design, and a nutritional education intervention embedded within the main trial.

The AGEP research sample consisted of vulnerable girls aged 10—19 years who had never been married at the time of the baseline survey and were residing in five rural and five urban sites within four provinces in Zambia: Lusaka, Central, Copperbelt, and North-Western. The sample was clustered at Census Supervisory Areas (CSAs), as delineated by the Zambia Central Statistical Office, which had been randomly selected within each site. The research instruments included a household survey and an adolescent survey. The household survey captured basic demographic information on all household members, as well as asset ownership and characteristics of the household's dwelling. The adolescent survey covered a wide range of topics, including, among others, questions on schooling, marriage, and childbearing histories. Adolescents' anthropometric data were also collected. Further details on AGEP, its evaluation design, and the embedded nutritional education intervention are reported elsewhere.[21–23]

The research protocol was reviewed and approved by the Population Council Institutional Review Board (PC-IRB #581), the University of Zambia's Research Ethics Committee (UNZA-REC #008-11-12), and the Zambian Ministry of Health, which granted authority to carry out the research. Informed consent was obtained from all participants. Informed consent was also obtained from parents or guardians of participants younger than 18 years old.

AGEP baseline (round 1) survey was conducted in July 2013–February 2014, and a total of 5235 never married girls aged 10–19 years were interviewed, representing an 88% response rate of the target sample. Follow-up surveys were conducted annually until 2017. The last survey round (round 5) is excluded from this study as no anthropometric measurements were collected due to budgetary constraints. Of the total baseline sample, 90%, 89%, and 83% were interviewed in rounds 2, 3, and 4, respectively. The analytical sample for our paper includes all respondents for whom we are able to construct relevant variables for at least two of these four survey rounds, excluding observations from rounds if respondents were pregnant at the time of the interview.

Explanatory variables

School-leaving was measured with a binary variable that is equal to 1 if the respondent was not enrolled in school at the time of the survey. *Marriage* was measured with three categories to indicate the respondents' marital status at the time of the survey: never married/lived with a partner (reference category), currently married/living with a partner, and previously married/lived with a partner (separated, divorced, or widowed). *Childbearing* was measured with four categories: never given birth at the time of the survey (reference category), had given birth and was breastfeeding at the time of the survey, had given birth but was no longer breastfeeding at the time of the survey, and had given birth but had no surviving children.

Work was measured as a binary variable that is equal to 1 if the respondent had done any work aside from household chores, whether paid or unpaid, in the past week. Household chores was measured with three categories indicating hours spent doing household chores (e.g., cooking, cleaning, laundry, and fetching firewood and water) the day before the interview: less than 2 h (reference category), 2 to less than 4 h, and 4 h or more. Household wealth was measured using principal components analysis (PCA) on 13 variables:[24] ownership of eight assets (electricity/solar panels, radio, cassette player, television, refrigerator, CD/digital music player, VCR/DVD player, and car/motorcycle), three dwelling characteristics (toilet facilities, floor material, and roof material), household members per sleeping room, and having means to obtain 1000 kwacha (currently about USD $75) in the case of need. Separately for rural and urban samples, the PCA was performed on the full baseline sample and wealth quintiles were generated. The scoring factors from the PCA and the baseline wealth quintile cutoffs were then applied to the data from the follow-up survey rounds. Three categories were constructed: the poorest (based on the lowest baseline quintile cutoff), the middle (reference category), and the richest (based on the highest baseline quintile cutoff).

Other control variables. As BMI is known to increase with age but at a decreasing rate, in addition to age, age squared was also included in the models. Age was measured as age at the time of the interview estimated from month and year of birth and date of the interview, not only to more accurately capture the age–BMI relationship but also to account for differences in time between surveys. Grade attainment was measured as a variable with the range 0–12 indicating the highest primary or secondary school grade a respondent had completed. Dietary diversity, used as a proxy indicator for higher micronutrient adequacy, is included in the models to account for potential differences in food availability and consumption. The following eight food groups consumed the day prior to the interview were measured: (1) grains, white roots, tubers, and plantains; (2) pulses, nuts, and seeds; (3) dairy; (4) meat, poultry, and fish; (5) eggs; (6) dark-green leafy vegetables; (7) vitamin A rich fruits and vegetables; and (8) other fruits and vegetables. Dietary diversity was measured as a score that is equal to the sum of groups, out of these eight food groups, consumed the day prior to the interview. It should be noted that the recommended measure for dietary diversity for women of reproductive age is based on 10 food groups.[25,26] These 10 food groups include all the foods listed in the eight groups above, but separate pulses from nuts and seeds, as well as other vegetables from other fruits; however, in the AGEP questionnaires for rounds 1–3, these foods were not asked for separately. Recent sickness was measured as a binary variable that is equal to 1 if the respondent reported having experienced any of the following symptoms in the past month: fever, night sweat, rapid weight loss, and recurring diarrhea, coughing or shortness of breath, vomiting, and fatigue or weakness. Controls for season of the year when the survey was conducted (dry cool, dry hot, and rainy) were included to account for potential seasonal factors that could affect food availability and prices. Models also controlled for exposure to AGEP and the nutritional education intervention by including two variables that measure the accumulated number of nutrition sessions and the accumulated number of other AGEP sessions the respondent had attended by the time of the interview. Models also controlled for rural/urban location, measured as a binary variable that is equal to 1 if the household in which the respondent was residing at the time of the interview was in a rural area. All variables included in the analytical models are time varying.

Body mass index

Girls' height was measured to the nearest 0.1 cm using SECA® portable stadiometers positioned on hard and flat surfaces. Girls were weighted on a digital scale standing up, weight was recorded to the nearest 0.1 kilogram. Girls' BMI was calculated as weight in kg/height in m^2.

Analytical approach

To investigate associations between BMI and school (S), marriage (M), and childbearing (B) status, while controlling for other variables (C), we use the following relation:

$$BMI_{it} = \beta_0 + \beta_1 S_{it} + \beta_2 M_{it} + \beta_3 B_{it} + \beta_4 C_{it} + a_i + u_{it} \quad (1)$$

where i is the respondent, t is the time (1, 2, 3, 4), a is an unobserved individual effect; and u is a random error. To eliminate the unobserved individual effect, a_i, we used the fixed-effects (or within) transformation;[27] that is, panel-level averages are removed from each side of Eq. (1), which, in turn, remove the a_i as it does not vary with time, and estimated the following model:

$$\left(BMI_{it} - \overline{BMI}_i\right) = \beta_0 + \beta_1\left(S_{it} - \bar{S}_i\right) + \beta_2\left(M_{it} - \bar{M}_i\right) + \beta_3\left(B_{it} - \bar{B}_i\right) + \beta_4\left(C_{it} - \bar{C}_i\right) + u_{it} - \bar{u}_i \quad (2)$$

The fixed-effects regressions were estimated with robust standard errors adjusted for the clusters in CSAs. In order to assess the appropriateness of the fixed-effects transformation, we reestimated the models using random-effects generalized least squares (GLS) regressions and conducted Hausman tests.

As a secondary analysis, we constructed categories for underweight, normal weight, and overweight and obesity using BMI-for-age Z-scores for girls aged 18 years or younger calculated using the 2007 WHO Reference and girls' ages in months, and absolute BMI cutoff points for girls aged 19 years or older. We combined the overweight and obesity categories because the prevalence of obesity is very low among the sample. We then estimated a fixed-effects multinomial logistic regression with robust standard errors using the user-generated `femlogit` command in Stata® (Ref. 28). To estimate this model, only respondents who experience a change in the BMI category are retained, as respondents who remain in the same BMI category throughout the period of observation do not contribute any information to the model. As overweight and obesity are generally more common in urban than in rural areas, we reestimated all models separately for the baseline rural and urban subsamples as supplementary analysis. We also conducted a series of checks to assess the robustness of our findings. Statistical significance was considered at the 95% level, and marginal statistical significance at the 90% level. All statistical analysis was conducted in Stata 15.1.

Results

Table 1 shows the composition of the analytical sample by survey round. Out of 5235 respondents interviewed at baseline, 4887 (93%) contribute a total of 17,702 observations across the four rounds: 70% of the analytical sample (3425 respondents) contribute four observations each, 22% (1078 respondents) contribute three observations each, and the remaining 8% (384 respondents) contribute two observations each.

To illustrate the density of major life transitions that adolescent girls face within a relatively short period of time, Figure 1 shows the distribution

Table 1. Analytical sample by AGEP survey round, AGEP 2013–2016

	Round 1	Round 2	Round 3	Round 4
Respondents interviewed at round	5235	4693	4633	4363
% of baseline (round 1) sample	100%	90%	89%	83%
– Pregnant at round	62	144	164	203
– Missing relevant data at round	101	94	100	27
– Only one round with relevant data	315	8	3	1
Respondents in analytical sample	4757	4447	4366	4132
% of baseline (round 1) sample	91%	85%	83%	79%

NOTE: Total analytical sample includes 17,702 observations from 4887 respondents, representing 93% of the total baseline sample.

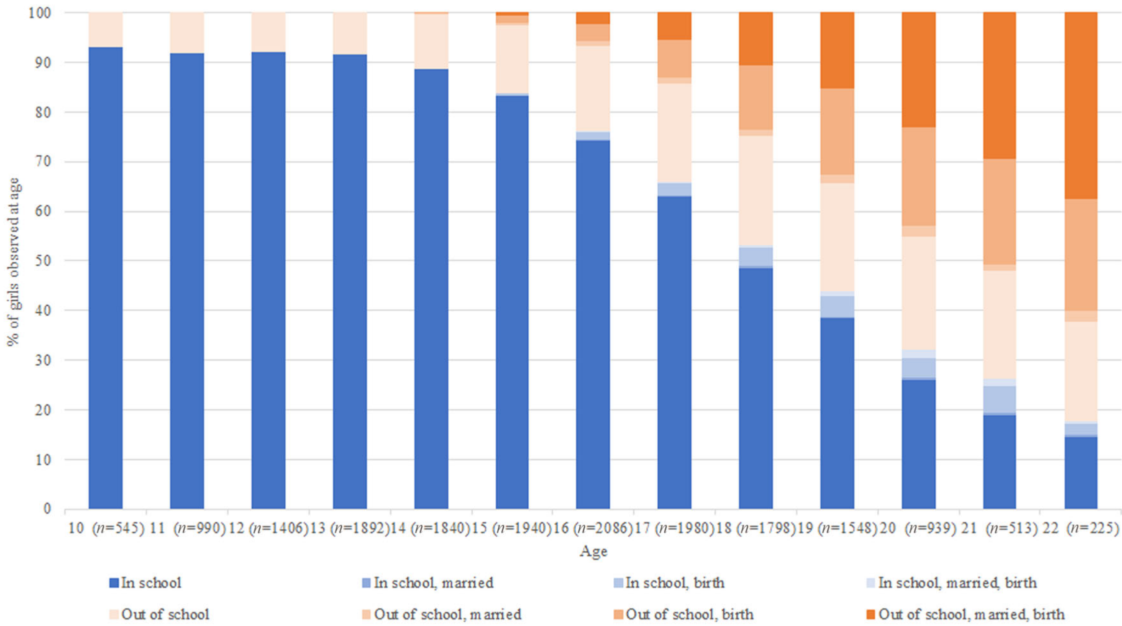

Figure 1. School, marriage, and birth status by age at last birthday, AGEP R1–R4 analytical sample pooled.

of school status, ever married, and given birth by age for the pooled analytical sample. During the early adolescent years (aged 10–14 years), the large majority of respondents were attending school and had neither been married nor given birth. This picture changes quickly, however, as respondents reach late adolescence and young adulthood; school attendance rates decrease steeply, while transition rates into first marriage and birth considerably increase.

Table 2 presents the means for the dependent and independent variables for respondents contributing to the analytical sample in each survey round. Mean BMI is increasing across time, and the prevalence of underweight is decreasing, while the prevalence of overweight and obesity are increasing as respondents become older. All explanatory variables are statistically significantly changing across time. Around 20% of respondents were out of school at round 1, this figure doubled by round 4. The sample was purposively never married at baseline and thus only around 5% had begun childbearing; however, in only 3 years, 16% had already experienced marriage and almost a quarter had begun childbearing.

BMI results

Table 3 presents results from fixed-effects linear regressions for BMI. To answer our research questions, we estimated a series of models to explore associations with school-leaving, marriage, and childbearing, and whether work, household chores, and household wealth explain these associations. Column (1) presents results from separate regressions estimated for each transitional variable of interest, adjusting for age and age squared only. Column (2) presents results from a regression including the three transitional variables simultaneously while controlling for age, age squared, grade attainment, dietary diversity, recent sickness, season, exposure to AGEP, and rural location. Column (3) presents results from a regression that adds the work, household chores, and household wealth indicators to the model in column (2).

Being out of school is not significantly associated with BMI on its own; however, when marriage and childbearing are included, being out of school is associated with a 0.17 higher BMI relative to being in school ($P < 0.001$). Marriage is negatively associated with BMI (currently married $\beta = -0.25$, $P < 0.01$ and previously married $\beta = -0.38$, $P < 0.01$) on its own; however, when school and childbearing statuses are also included, the coefficient for currently married is close to zero, and while the coefficient for previously married remains negative, it is not statistically significant. Having given birth is negatively associated with BMI, whether

Table 2. **Means and standard deviations (SD) for dependent and explanatory variables by survey round and analytical sample, AGEP 2013–2016**

	Round 1 aged 10−19 ($n = 4757$)	Round 2 aged 11−20 ($n = 4447$)	Round 3 aged 12−21 ($n = 4366$)	Round 4 aged 13−22 ($n = 4132$)	P
Dependent variables					
BMI, mean (SD)	19.4 (3.2)	20.0 (3.2)	20.6 (3.2)	21.1 (3.1)	0.000
BMI categories					
Underweight, %	15.0	12.8	12.6	10.9	0.000
Normal, %	78.4	78.4	77.6	77.6	0.710
Overweight, %	6.1	8.0	8.8	10.2	0.000
Obese, %	0.6	0.8	1.0	1.3	0.000
Transitional variables					
Out of school, %	19.6	23.6	31.3	39.5	0.000
Marital status					
Never married, %	100.0	96.1	90.3	83.9	0.000
Currently married, %	0.0	3.2	8.0	13.4	0.000
Previously married, %	0.0	0.7	1.7	2.7	0.000
Childbearing status					
Never given birth, %	94.8	90.1	82.7	75.1	0.000
Given birth, breastfeeding, %	2.9	5.6	10.7	13.6	0.000
Given birth, not breastfeeding, %	2.0	3.9	6.1	10.5	0.000
Given birth, no surviving children, %	0.2	0.5	0.6	0.8	0.001
Work and wealth variables					
Works, %	21.0	26.0	27.1	34.9	0.000
Household chores					
Less than 2 h, %	57.2	51.8	51.4	49.3	0.000
Two to less than 4 h, %	33.4	37.5	38.0	37.2	0.000
Four hours or more, %	9.4	10.7	10.6	13.5	0.000
Household wealth					
Poorest, %	20.9	16.2	14.3	14.2	0.000
Middle, %	58.8	56.4	55.7	53.8	0.000
Richest, %	20.3	27.3	30.0	32.1	0.000
Other control variables					
Age, mean (SD)	14.7 (2.7)	15.5 (2.7)	16.6 (2.7)	17.5 (2.7)	0.000
Grade attainment, mean (SD)	5.4 (2.5)	5.8 (2.4)	6.8 (2.3)	7.3 (2.2)	0.000
Dietary diversity score, mean (SD)	3.2 (1.5)	3.6 (1.5)	3.8 (1.5)	4.0 (1.5)	0.000
Sick last month, %	35.7	41.0	38.8	45.1	0.000
Season					
Dry cool, %	23.0	38.4	38.8	48.4	0.000
Dry hot, %	39.2	36.0	31.8	31.1	0.000
Rainy, %	37.8	25.6	29.4	20.5	0.000
AGEP nutrition sessions, mean (SD)	0.0 (0.0)	0.5 (1.3)	0.8 (2.1)	0.9 (2.2)	0.000
AGEP other sessions, mean (SD)	0.0 (0.0)	10.9 (13.6)	21.0 (28.4)	22.7 (31.2)	0.000
Rural location, %	44.3	41.6	41.6	39.2	0.001

NOTE: Differences across survey rounds were assessed using Wald χ^2 tests from random-effects GLS regressions with standard errors adjusted for clusters in CSAs.

currently breastfeeding or not, and these associations persist when school and marital status are included (breastfeeding $\beta = -0.59$, $P < 0.001$ and not breastfeeding $\beta = -0.49$, $P < 0.001$). Having given birth but having no surviving children is also negatively associated with BMI, but not statistically significant. Results for school, marriage, and childbearing remain basically unchanged when

Table 3. Results from fixed-effects (within) regressions for BMI, coefficients, and 95% confidence intervals (CI)

	(1)		(2)		(3)	
	Coef	95% CI	Coef	95% CI	Coef	95% CI
Transitional variables						
Out of school	0.066	(−0.024 to 0.155)	0.172***	(0.084 to 0.259)	0.174***	(0.087 to 0.261)
Marital status						
Never married (ref)						
Currently married	−0.254**	(−0.422 to −0.087)	−0.002	(−0.171 to 0.167)	0.002	(−0.167 to 0.170)
Previously married	−0.375**	(−0.635 to 0.115)	−0.196	(−0.447 to 0.056)	−0.188	(−0.436 to 0.059)
Childbearing status						
Never given birth (ref)						
Breastfeeding	−0.551***	(−0.697 to −0.405)	−0.592***	(−0.745 to −0.439)	−0.593***	(−0.747 to −0.439)
Birth, not breastfeeding	−0.487***	(−0.653 to −0.321)	−0.489***	(−0.659 to −0.319)	−0.485***	(−0.654 to −0.315)
Birth, no surviving children	−0.298	(−0.766 to 0.169)	−0.280	(−0.751 to 0.191)	−0.270	(−0.741 to 0.200)
Work and wealth variables						
Works					−0.060**	(−0.104 to −0.016)
Household chores						
Less than 2 h (ref)						
Two to less than 4 hours					0.049*	(0.002 to 0.096)
Four hours or more					0.044	(−0.025 to 0.112)
Household wealth						
Middle (ref)						
Poorest					−0.072*	(−0.132 to −0.013)
Richest					0.109***	(0.055 to 0.162)
F-stat			429.14***		358.37***	
Rho			0.84		0.84	
F-test for individual effects			18.78***		18.7***	
Hausman test: χ^2			147.04***		166.61***	

NOTE: Column (1) presents results from separate regressions for each transitional variable adjusted for age and age squared. Column (2) presents results from a regression that included the three transitional variables and controlled for age, age squared, grade attainment, dietary diversity, sick last month, season, AGEP nutrition and other sessions attended, and rural location. Column (3) presents results from a regression that included the three transitional variables plus the work and wealth variables, and controlled for age, age squared, grade attainment, dietary diversity, sick last month, season, AGEP nutrition, and other sessions attended, and rural location. All models were estimated with robust standard errors adjusted for clusters in CSAs. Sample $n = 4887$ girls; observations $n = 17{,}702$. $^{***}P < 0.001$, $^{**}P < 0.01$, and $^{*}P < 0.05$.

work, household chores, and household wealth are included in the model (column (3)). The rho suggests that most (0.84) of the variation in BMI is related to inter-respondent differences in BMI. The *F*-test for individual effects indicates that there are significant individual effects (implying that pooled regressions would not be appropriate). To test the appropriateness of our models, we reestimated all models with fixed effects but without robust standard errors and compared with identical models estimated with random effects (available upon request). Hausman tests indicate the null hypothesis that the random-effects estimates are consistent is rejected in all models.

Results from the full model for BMI estimated separately for the baseline rural and urban subsamples show that being out of school is associated with a higher BMI in both cases; being currently married is marginally associated with a higher BMI in the urban sample; and while childbearing is associated with a lower BMI in both samples, the associations are twice as large in the rural than in the urban sample (Table S1, online only).

BMI categories results

Table 4 presents results from the fixed-effects multinomial logistic regression for BMI categories. The reference category is normal BMI. Out of 4887 respondents in the analytical sample, 1328 (27%)

Table 4. Results from fixed-effects multinomial logistic regression for BMI categories, relative-risk ratios (RRR), and 95% confidence intervals (CI)

	Underweight		Overweight/obesity	
	RRR	95% CI	RRR	95% CI
Transitional variables				
Out of school	0.813	(0.584–1.132)	1.566*	(1.102–2.226)
Marital status				
Never married (ref)				
Currently married	2.479**	(1.431–4.295)	1.448	(0.769–2.726)
Previously married	5.197**	(1.957–13.803)	0.970	(0.391–2.410)
Childbearing status				
Never given birth (ref)				
Breastfeeding	2.039*	(1.157–3.594)	0.322***	(0.172–0.601)
Birth, not breastfeeding	0.912	(0.406–2.046)	0.511†	(0.257–1.018)
Birth, no surviving children	1.035	(0.269–3.979)	0.385	(0.106–1.401)
Work and wealth variables				
Works	1.305*	(1.060–1.606)	0.929	(0.728–1.186)
Household chores				
Less than 2 h (ref)				
Two to less than 4 hours	1.024	(0.848–1.236)	1.319*	(1.061–1.640)
Four hours or more	0.994	(0.718–1.375)	1.403*	(1.002–1.963)
Household wealth				
Middle (ref)				
Poorest	1.269†	(0.978–1.647)	1.010	(0.706–1.446)
Richest	1.010	(0.778–1.312)	1.285†	(0.971–1.700)
Wald χ^2	292.9***			
Log pseudolikelihood	−1641.51			

NOTE: Model controlled for age, age squared, grade attainment, dietary diversity, sick last month, season, AGEP nutrition and other sessions attended, and rural location. Model was estimated with robust standard errors. Normal BMI is the reference category. Sample $n = 1328$ girls; observations $n = 4938$. $^{***}P < 0.001$, $^{**}P < 0.01$, $^{*}P < 0.05$, and $^{\dagger}P < 0.1$.

experienced a change of BMI category during the period of observation. Results show that being out of school is associated with higher odds of being overweight/obese relative to being in school (OR = 1.57; $P < 0.5$). Being currently married (OR = 2.48, $P < 0.01$) and having been married (OR = 5.20, $P < 0.01$) are both associated with higher odds of being underweight relative to having never been married. Being currently married is also associated with higher odds of being overweight/obese but is not statistically significant. Breastfeeding is significantly associated with higher odds of being underweight (OR = 2.04, $P < 0.05$) and lower odds of being overweight/obese (OR = 0.32, $P \leq 0.001$).

Results of the regressions estimated separately for the baseline rural and urban subsamples (Tables S2 and S3, online only) show that being out of school is marginally significantly associated with higher odds of being overweight/obese in both cases; current and previous marriage are both associated with higher odds of being underweight in the rural sample, while only previously married is marginally associated with higher odds of being underweight in the urban sample; and breastfeeding is significantly associated with higher odds of being underweight and all childbearing categories are significantly associated with lower odds of overweight/obesity in the rural sample.

Robustness considerations

As the period of observation is relatively short, we do not observe a large majority of girls' transition out of school, into marriage and childbearing. To investigate whether our findings change when higher proportions of adolescents and young women have experienced these transitions, we reestimated the full models for BMI and BMI

Table 5. Summary of findings comparing associations for the full sample with the baseline sample of 15- to 19-year-olds

	Full sample			Baseline sample of 15- to 19-year-olds		
		BMI categories			BMI categories	
	BMI	Underweight	Overweight/obesity	BMI	Underweight	Overweight/obesity
Transitional variables						
Out of school	(+)		(+)	(+)		(+)
Currently married		(+)			(+)	(+)
Previously married		(+)			(+)	
Breastfeeding	(−)	(+)	(−)	(−)		(−)
Birth, not breastfeeding	(−)		(−)	(−)		(−)
Birth, no surviving children						
Work and wealth variables						
Works	(−)	(+)				
Two to less than 4 h of chores	(+)		(+)	(+)		(+)
Four or more hours of chores			(+)	(+)		(+)
Poorest	(−)	(+)		(-)		
Richest	(+)		(+)	(+)		

NOTE: Models controlled for age, age squared, grade attainment, dietary diversity, sick last month, season, AGEP nutrition and other sessions attended, and rural location. Models were estimated with robust standard errors adjusted for clusters in CSAs. BMI full sample $n = 4887$ girls; observations $n = 17{,}702$. BMI categories full sample $n = 1328$ girls; observations $n = 4938$. BMI baseline sample of 15- to 19-year-olds $n = 2386$ girls; observations $n = 8381$. BMI categories baseline sample of 15- to 19-year-olds $n = 621$ girls; observations $n = 2258$.

categories for the subsample of girls who were aged 15–19 years at baseline and thus were more likely to have experienced the transitions out of school, into marriage and childbearing. Table 5 presents summary findings of the associations found in the models using the full sample and in the models limited to the baseline sample of 15- to 19-year-olds for our key variables. Being out of school is consistently associated with a higher BMI and higher odds of overweight/obesity. Ever been married is consistently associated with higher odds of underweight; however, being currently married is also associated with higher odds of overweight/obesity for the subsample of baseline aged 15—19 years. Having living children, whether breastfeeding or not, is consistently associated with a lower BMI and lower odds of overweight/obesity; but breastfeeding is not associated with higher odds of underweight among the subsample of baseline 15—19 years.

Finally, we conducted three additional robustness checks. First, we estimated linear probability models with fixed effects for underweight and overweight/obesity separately. Unlike the fixed-effects multinomial logistic models, these models retain all observations in the analytical sample. Second, we reestimated all our models using a balanced panel that is, including only respondents who contributed the four observations to the analytical sample. Third, we reestimated all of our models controlling for age categories instead of age and age squared. In all cases, while the point estimates vary slightly, the findings remain unchanged (results are available upon request).

Discussion

School-leaving, marital transitions, and childbearing may influence the nutritional status of AGYW through their impact on dietary intake, physical activity, and general health. The relationships between adolescent girls' nutritional status and their transitions out of school, into marriage and motherhood are complex as they can be bidirectional and operate in opposing ways. On one hand, undernutrition can have a negative effect on academic performance and thus be a driver of early school dropout.[29,30] On the other hand, adolescent girls' lives may become more sedentary when they stop attending school resulting in weight gain. We explored these relationships using longitudinal data from a cohort of adolescent girls in Zambia.

In addition to being able to control for a number of time-varying factors, the longitudinal data allowed us to use fixed-effects models that control for all individual-level constant factors, observed and unobserved, that could have an effect on BMI and nutritional status.

The findings reviewed in our paper indicate that school-leaving, marital status, and childbearing are associated with AGYW's nutritional status in diverse ways. School-leaving is associated with higher BMI and increases the risk of overweight/obesity. This finding was expected as the lives of young women are likely to become more sedentary when they stop attending school, while eating patterns may shift with more ready access to food. We were expecting marriage to be positively associated with overweight/obesity, as was noted in other studies,[16–18] but we found that marriage increases BMI only in urban areas and among older girls. In rural areas, marriage was found to increase the risk of being underweight. The establishment of a new household, as well as power and status within the marital household, may have a role to play;[31] further research is needed to understand what causes rural married young women to be at higher risk of undernutrition.

Our finding that AGYW who have experienced a marriage dissolution are at a higher risk of undernutrition should also be explored further and suggest an at-risk population that could be targeted for nutritional interventions. Motherhood is associated with lower BMI and lower risk of being overweight/obese, particularly among breastfeeding young mothers, which was not surprising given existing evidence from previous studies in the region.[19,20] While current work, time spent doing household chores, and household wealth are associated with AGYW's nutritional status, these associations do not explain the associations observed with school-leaving, marriage, and childbearing.

Understanding how transitions to adulthood are related to young women's nutritional status is highly relevant in this region as the burdens of under- and overnutrition are increasingly coexisting,[6,32,33] and obesity is a health concern particularly affecting women.[34] Evidence from our paper identified characteristics among AGYW that would be useful for targeted nutritional interventions and social behavior change programming, including girls leaving school (at risk for being overweight/obese), recently married, and young women undergoing a marital separation (higher risk of undernutrition), and young mothers and their children (at higher risk of undernutrition). Targeted interventions to improve nutritional statuses and downstream health outcomes may consist of nutrition-specific interventions, such as micronutrient supplementation,[35] or integrated, multisectoral interventions, such as the AGEP program, which embedded a nutritional curriculum into a nutrition-sensitive program that included a female empowerment component aimed at delaying school dropout and marriage and a sexual and reproductive health component seeking to delay pregnancy. Programs and policies that aim to improve the nutritional status of AGYW need to be aware of the density of transitions during this period and how these transitions may intersect.

Study limitations

Our study has some important limitations. First, while the sample is representative of girls living in rural settings, it is not representative of all girls living in urban settings but only of those most vulnerable according to the vulnerability definition used to select girls for AGEP. Second, the sample was purposively never married at baseline. While this is not problematic for the younger cohort, it means that for the older cohort, the sample is biased toward girls who had not yet been married and who could be different from girls who had already entered marriage. Third, the data are part of a randomized controlled trial where some respondents were exposed to a series of interventions and others were not. Although we controlled for actual program exposure in our models to mitigate bias from exposure to the intervention, it is possible that some bias remains. Fourth, our findings could also be biased owing to attrition from the study. To assess potential attrition bias, we compared baseline characteristics of respondents by inclusion in the analytical sample (see Tables A1 and A2 in the Appendix, online only). Results from multivariate models indicate that being older and from poorer households significantly increased, while grade attainment significantly decreased, the odds of exclusion from the analytical sample. Ever given birth and rural location were both marginally significantly associated with lower odds of exclusion from the analytical sample. Nonetheless, our study is, to our knowledge, the first to simultaneously investigate how school-leaving, marriage, and childbearing influence the nutritional status of AGYW in a sub-Saharan African country.

Acknowledgments

This study was supported by the New York Academy of Sciences. The Adolescent Girls Empowerment Program data collection was funded by the UK Government's Department for International Development Grant #40049678. We thank attendees at a staff meeting on February 25, 2019 at the Population Council in Nairobi and at the Adolescent Nutrition Grantee Meeting on May 24, 2019 at the New York Academy of Sciences, and Yehuda Izhakian for valuable comments and suggestions. The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding institutions.

Author contributions

P.C.H., E.S.H., and K.A. designed the Adolescent Girls Empowerment Program study. E.S.H., P.C.H., and K.S. contributed to the conceptualization of this paper. E.S.H. conducted the data analysis and drafted the manuscript. P.C.H., K.S., and K.A. reviewed the draft manuscript. All authors read and approved the final manuscript.

Supporting information

Additional supporting information may be found in the online version of this article.

Table A1. Means and standard deviations (SD) for select characteristics measured at baseline by inclusion in analytical sample.

Table A2. Results from logistic regressions for exclusion from analytical sample, odds ratios (OR), and 95% confidence intervals (CI).

Table S1. Results from fixed-effects (within) regressions for BMI by rural and urban baseline samples, coefficients, and 95% confidence intervals (CI).

Table S2. Results from fixed-effects multinomial logistic regression for BMI categories, rural baseline sample, odds ratios (OR), and 95% confidence intervals (CI).

Table S3. Results from fixed-effects multinomial logistic regression for BMI categories, urban baseline sample, odds ratios (OR), and 95% confidence intervals (CI).

Competing interests

The authors declare no competing interests.

References

1. Han, Z., S. Mulla, J. Beyene, *et al.* 2011. Maternal underweight and the risk of preterm birth and low birth weight: a systematic review and meta-analyses. *Int. J. Epidemiol.* **40:** 65–101.
2. Ramakrishnan, U., F. Grant, T. Goldenberg, *et al.* 2012. Effect of women's nutrition before and during early pregnancy on maternal and infant outcomes: a systematic review. *Paediatr. Perinat. Epidemiol.* **26:** 285–301.
3. Black, R.E., C.G. Victora, S.P. Walker, *et al.*; Maternal and Child Nutrition Study Group. 2013. Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet* **382:** 427–451.
4. Katona, P. & J. Katona-Apte. 2008. The interaction between nutrition and infection. *Clin. Infect. Dis.* **46:** 1582–1588.
5. Dobner, J. & S. Kaser. 2018. Body mass index and the risk of infection–from underweight to obesity. *Clin. Microbiol. Infect.* **24:** 24–28.
6. NCD Risk Factor Collaboration (NCD-RisC). 2017. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. *Lancet* **390:** 2627–2642.
7. Lobstein, T., L. Baur & R. Uauy. 2004. Obesity in children and young people: a crisis in public health. *Obes. Rev.* **5:** 4–85.
8. Reilly, J. & J. Kelly. 2011. Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: systematic review. *Int. J. Obes.* **35:** 891–898.
9. Central Statistical Office (CSO) [Zambia], Ministry of Health (MOH) [Zambia], and ICF International. 2014. *Zambia demographic and health survey 2013–14*. Rockville, MD: Central Statistical Office, Ministry of Health, and ICF International.
10. Mwaikambo, S.A., G.H. Leyna, J. Killewo, *et al.* 2015. Why are primary school children overweight and obese? A cross sectional study undertaken in Kinondoni district, Dar-es-salaam. *BMC Public Health* **15:** 1269.
11. Baalwa, J., B.B. Byarugaba, E.K. Kabagambe & A.M. Otim. 2010. Prevalence of overweight and obesity in young adults in Uganda. *Afr. Health Sci.* **10:** 367–373.
12. Lloyd, C.B. & B.S. Mensch. 2008. Marriage and childbirth as factors in dropping out from school: an analysis of DHS data from sub-Saharan Africa. *Popul. Stud. (Camb.)* **62:** 1–13.
13. Petroni, S., M. Steinhaus, N. Stevanovic Fenn, *et al.* 2017. New findings on child marriage in sub-Saharan Africa. *Ann. Glob. Health* **83:** 781–790.
14. Fu, H. & N. Goldman. 1996. Incorporating health into models of marriage choice: demographic and sociological perspectives. *J. Marriage Fam.* **58:** 740–758.

15. Kaler, A. 2004. AIDS-talk in everyday life: the presence of HIV/AIDS in men's informal conversation in Southern Malawi. *Soc. Sci. Med.* **59:** 285–297.
16. Dinour, L., M.M. Leung, G. Tripicchio, *et al.* 2012. The association between marital transitions, body mass index, and weight: a review of the literature. *J. Obes.* **2012**. https://doi.org/10.1155/2012/294974.
17. Schmeer, K.K. 2012. Union transitions and changes in BMI among adults in Mexico. *J. Health Soc. Behav.* **53:** 263–275.
18. Pereko, K.K., J. Setorglo, W.B. Owusu, *et al.* 2012. Overnutrition and associated factors among adults aged 20 years and above in fishing communities in the urban Cape Coast Metropolis, Ghana. *Public Health Nutr.* **16:** 591–595.
19. Gewa, C.A., M. Oguttu & N.S. Yandell. 2012. Maternal nutrition in rural Kenya: health and socio-demographic determinants and its association with child nutrition. *Matern. Child Nutr.* **8:** 275–286.
20. Gewa, C.A., T.F. Leslie & L.R. Pawloski. 2012. Geographic distribution and socio-economic determinants of women's nutritional status in Mali households. *Public Health Nutr.* **16:** 1575–1585.
21. Hewett, P.C., K. Austrian, E. Soler-Hampejsek, *et al.* 2014. Adolescent girls empowerment programme: research and evaluation baseline technical report. Population Council, Lusaka, Zambia.
22. Hewett, P.C., K. Austrian, E. Soler-Hampejsek, *et al.* 2017. Cluster randomized evaluation of Adolescent Girls Empowerment Programme (AGEP): study protocol. *BMC Public Health* **17:** 386.
23. Hewett, P.C., J. Digitale, E. Soler-Hampejsek, *et al.* 2017. Enhanced evaluation of an educational nutritional curriculum among adolescent girls in Zambia: final study report. Population Council.
24. Filmer, D. & L.H. Pritchett. 2001. Estimating wealth effects without expenditure data–or tears: an application to educational enrollments in states of India. *Demography* **38:** 115–132.
25. Kennedy, G., T. Ballard & M. Dop. 2010. Guidelines for measuring household and individual dietary diversity. Nutrition and Consumer Protection Division, Food and Agriculture Organization of the United Nations.
26. Food and Agriculture Organization. 2016. FHI 360 Minimum dietary diversity for women: a guide to measurement. FAO, Rome.
27. Wooldridge, J.M. 2001. *Econometric Analysis of Cross Section and Panel Data*. Cambridge, MA: MIT Press.
28. Pforr, K. 2014. Femlogit—implementation of the multinomial logit model with fixed effects. *Stata J.* **14:** 847–862.
29. Glewwe, P., H.G. Jacoby & E.M. King. 2000. Early childhood nutrition and academic achievement: a longitudinal analysis. *J. Pub. Econ.* **81:** 345–368.
30. Taras, H. 2005. Nutrition and student performance at school. *J. Sch. Health* **75:** 199–213.
31. Hindin, M.J. 2005. Women's input into household decisions and their nutritional status in three resource-constrained settings. *Public Health Nutr.* **9:** 485–493.
32. Akseer, N., S. Al-Gashm, S. Mehta, *et al.* 2005. Global and regional trends in the nutritional status of young people: a critical and neglected age group. *Ann. N.Y. Acad. Sci.* **1393:** 3–20.
33. Humbwavali, J.B., C. Giugliani, I.C.M. da Silva & B.B. Duncan. 2018. Temporal trends in the nutritional status of women and children under five years of age in sub-Saharan African countries: ecological study. *Sao Paulo Med. J.* **136:** 454–463.
34. Development Initiatives . 2017. Global nutrition report 2017: nourishing the SDGs. Development Initiatives, Bristol, UK.
35. Haider, B.A. & Z.A. Bhutta. 2017. Multiple-micronutrient supplementation for women during pregnancy. *Cochrane Database Syst. Rev.* **4:** CD004905.