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The longitudinal relationship between community programmes and policies to prevent childhood obesity and BMI in children: the Healthy Communities Study

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Summary

Background: Although a national epidemic of childhood obesity is apparent, how community-based programmes and policies (CPPs) affect this outcome is not well understood.

Objectives: This study examined the longitudinal relationship between the intensity of CPPs in 130 communities over 10 years and body mass index (BMI) of resident children. We also examined whether these relationships differ by key family or community characteristics.

Methods: Five thousand one hundred thirty-eight children in grades K-8 were recruited through 436 schools located within 130 diverse US communities. Measures of height, weight, nutrition, physical activity and behavioural and demographic family characteristics were obtained during in-home visits. A subsample of families consented to medical record review; these weight and height measures were used to calculate BMI over time for 3227 children. A total of 9681 CPPs were reported during structured interviews of 1421 community key informants, and used to calculate a time series of CPP intensity scores within each community over the previous decade. Linear mixed effect models were used to assess longitudinal relationships between childhood BMI and CPP intensity.

Results: An average BMI difference of 1.4 kg/m^2 (p-value < 0.01) was observed between communities with the highest and lowest observed CPP intensity scores, after adjusting for community and child level covariates. BMI/CPP relationships differed significantly by child grade, race/ethnicity, family income and parental education; as well as community-level race/ethnicity.

Conclusions: These results indicate that, over time, more intense CPP interventions are related to lower childhood BMI, and that there are disparities in this association by sociodemographic characteristics of families and communities.

Keywords: Body mass index, community programmes and policies, health disparities, longitudinal.

Abbreviations: Body Mass Index or Body Mass Indices, (BMI); Community-based Programme or Policy, (CPP); Community-based Programmes and Policies, (CPPs); Healthy Communities Study, (HCS); Medical Record Review, (MRR); Socio-economic Status, (SES)

Introduction

Childhood obesity is a major public health concern in the USA, with 17% of children and adolescents aged 2–19 years being obese (1). Childhood obesity is related to many negative health consequences (e.g. hypertension, type 2 diabetes, heart disease) (2). Although overall obesity prevalence has plateaued in recent years (1,3), it continues to be highly prevalent among low income and minority groups (4).

Obesity results from the interplay among biological, social, behavioural, cultural, environmental and economic factors; individual (e.g. genetics, level of physical activity), family (e.g. parenting style, home nutrition environment), school (e.g. policies on nutrition and physical activity) and environmental factors (e.g. access to healthy foods, parks and recreational areas) all contribute to this outcome (5). How these factors contribute to childhood obesity and disparities in obesity risk between different population groups is poorly understood.

Leading health organizations including the National Academy of Medicine (formerly the Institute of Medicine) and the World Health Organization recommend comprehensive and multi-level approaches for obesity prevention, including programmes and policies at the community level (6,7). Recent reviews provide evidence that comprehensive programmes and policies are more promising for reducing obesity in children than less comprehensive approaches (8–12). Guidance on community efforts to promote healthy environments for children include recommendations to deliver programmes, policies and environmental changes of sufficient quantity and intensity – including strong behaviour change strategies of long duration and wide reach (13). A growing number of local, state and national policies and programmes have been implemented to support healthy diets and physical activity (13,14). Studies to date have typically focused on interventions that are child-based or family-based or implemented in school settings, and have reached a relatively small number of children (15). The effects of variations in community efforts – delivered over time, through multiple sectors, in different contexts – have not been well documented (16).

The present study used a longitudinal design to examine the relationship over the past decade between the intensity of community-based programmes and policies (CPPs) in 130 communities and body mass index (BMI) of resident children. We also examined whether this relationship differed by individual, household or community factors.

Methods

The Healthy Communities Study (HCS) assessed relationships between characteristics of programmes and policies targeting childhood obesity and children's BMI, dietary and physical activity behaviours (17). The HCS combined a stratified probability-based sample of 102 communities (defined as public high school catchment areas) that ensured diversity across demographics and CPPs, with a purposeful sample of 28 'certainty' communities identified by an expert panel as having innovative and/or promising CPPs related to childhood obesity (18).

The study, implemented from 2013–2015, included two primary components aimed at (i) characterizing how childhood obesity programmes and policies have evolved within each community over the previous decade (19) and (ii) developing a longitudinal history of BMI via medical record review (MRR) and current anthropometric assessments (height, weight, BMI) (20), along with measures of physical activity, nutrition and covariates for a sample of children from each community recruited through schools (18). The protocols for recruitment and enrolment of school districts, schools and participant families into the HCS are documented elsewhere (18).

A total of 9681 CPPs occurring in the past decade were identified and characterized through interviews with approximately 10–14 key informants per community (e.g. school principals, government staff) and supplemented via document abstraction (e.g. reviews of reports) (19). Retrospective collection of CPP information from multiple sources allowed for each CPP to be documented for the prior decade. Each CPP was characterized by attributes related to its intensity (i.e. behaviour change strategy, duration, reach) and other dimensions (e.g. target behaviour, sector through which delivered). CPP intensity scores that weighted CPPs based on behaviour change strategy, duration and reach were developed for each community for each year over the prior decade. Higher weights were assigned to CPPs that reached a greater proportion of the community population (reach); that were ongoing rather than infrequent or one-time events (duration); and that modified policies or access, barriers and opportunities, as compared with those that provided information or enhanced skills (strategy). The attributes of each observed CPP were scored as high (1), medium (0.55) or low (0.1) for each of these three dimensions, while allowing for change in these dimensional scores over time to account for the evolution of each CPP. A weighted score for each CPP was averaged over the three dimensions, and then summed to create a single, annual intensity score within each community. Additional details on the protocols for constructing the CPP Intensity Score are provided elsewhere (19).

Data on 5138 child/parent pairs were collected at home visits by trained field data collection personnel. Height and weight information was abstracted from paediatric healthcare provider records of consenting families, yielding 31,620 MRR BMI measures among 3317 children (20). Statistical process control was applied to a time series of observed BMI for each child, and was used to eliminate individual MRR data points that were grossly inconsistent with the BMI data from the household visit and/or a series of other MRR data points observed on the same child. This process removed 1512 extreme BMI outliers and 90 children from the MRR dataset (protocol provided in online supplement). When combined with data from the household visit, the analysis dataset represents 33,335 BMI observations among 3227 children.

Linear mixed effects models (21) were used to assess longitudinal relationships between childhood BMI and CPP intensity scores, while adjusting for the anticipated correlation among participants from within the same school/community, and repeated measures on children (18). Due to missing child/family covariate information and missing dates of CPP onset or completion from key informant interviews, multiple imputation techniques were utilized with results integrated across 20 imputed datasets (22).

Smooth spline curves were fit to discrete yearly CPP scores within each community to facilitate estimation of the CPP score matched in time with each BMI measurement, as well as time-lagged effects (e.g. matching the child's BMI to the CPP score from 24 months prior) and cumulative effects (e.g. integrating the area under the CPP curve over the preceding 24-month period). These continuous community-specific CPP intensity scores were standardized across all communities and all years to range from '0' (lowest intensity) to '1' (highest intensity), providing a consistent interpretation of CPP intensity score across all models investigated.

A minimally adjusted statistical model combined BMI measures from both the in-home visit and medical records; explaining these data as a function of the time-varying intensity of within-community CPPs as follows:

$$
\begin{aligned}
BMI_{ijk} = {} & f\left(Age_{ijk}, Gender_{ij}, \beta_0\right) + \beta_1 \cdot CPP_{ijk} \\
& + \beta_2 \cdot Height_{ijk} + \delta_{i0} + \delta_{i1} \cdot CPP_{ijk} + \alpha_{ij0} \\
& + \alpha_{ij1} \cdot Age_{ijk} + \varepsilon_{ijk},
\end{aligned}
$$

where the k^{th} observed BMI measurement for the j^{th} study participant in the i^{th} community is expressed as a function of gender-specific (cubic polynomial) age curves and the temporally matched community programme/policy intensity score (CPP_{ijk}), after adjusting for the child's height, random-effect community-specific BMI/CPP relationships (δ_{i0} and δ_{i1}) and random-effect child-specific BMI growth trajectories as a function of age (α_{ij0} and α_{ij1}).

The β_1 parameter captures the association between CPP intensity and childhood BMI, and is interpreted as the average change in BMI between a community rated as having maximum intensity of programmes and policies (1) and rated as having minimal intensity (0). A fully adjusted model included other child/family level factors (related to ethnicity, family income, parental employment status and seasonality) and community factors (related to education, race and poverty) to assess the covariate adjusted relationship between childhood BMI and CPP intensity scores.

Because it may take time for the impact of community interventions on child BMI to be realized, we examined temporal relationships. A series of 64 CPP intensity scores were explored across a range of time-lagged values and cumulative periods of time (0, 3, 6, 12, 18, 24, 30 and 36-month values for each). Likelihood statistics (23) from the minimally and fully adjusted models were combined to assess which specific time-lag and cumulative period for CPPs was optimal for predicting childhood BMI in the HCS. A CPP intensity score based on a 24-month lag (i.e. community score matched with BMI 24 months later) and a 24-month cumulative period was identified as optimal. The supplementary online material provides results for the CPP variable with no time-lag, which had significantly lower likelihood statistics.

Interaction terms were added to the models to assess whether the relationship between CPP and BMI differed by child and community factors such as gender, income and race/ethnicity. Type-III *F*-tests (and *t*-tests) were used to assess the statistical significance of the relationship between (and within) each subpopulation.

Results

Child participants

The full sample of 5138 children in the HCS and the subset of 3227 children with longitudinal BMI data from MRR were relatively evenly distributed by gender, grade level and Hispanic ethnicity (Table 1). Over 40% were Hispanic, nearly a fifth were African American and nearly a third reported annual household income below $20,000. Although the demographic characteristics of the sample with and without abstracted data were similar, the proportion of HCS children with MRR data increased with income and as children aged. Prevalence of overweight was similar between those with and without MRR data, except for children in grades 3–5. On average, there were 9.33 abstracted BMI measures per child, with less than 1 year between successive measures (0.77 years), and covering a time period (on average) from 0.55 to 4.93 years prior to the household visit (Table 1).

Table 1 Descriptive summary of child-level BMI data from the Healthy Communities Study

Covariate	Level	Sample Size Participants		χ^2 Test*	Medical Record Review (MRR) Mean Distributional Statistics**				Household Visit Childhood Prevalence of Overweight Summary Statistics***				
		with MRR	without MRR	p-value	# of Medical Records	Years from first MR	Years from last MR	Years between MR	Participants with MRR $\hat{p}$	Participants with MRR 95% CI	Participants without MRR $\hat{p}$	Participants without MRR 95% CI	z-test* p-value
All Children		3227	1911	n.a.	9.33	4.93	0.55	0.77	0.594	(0.58,0.61)	0.592	(0.57,0.61)	0.906
Gender	Male	1573	951	0.498	9.37	4.89	0.51	0.76	0.586	(0.56,0.61)	0.588	(0.56,0.62)	0.889
	Female	1654	960		9.29	4.96	0.59	0.78	0.602	(0.58,0.63)	0.596	(0.56,0.63)	0.771
Grade	K-2	1250	685	0.038	10.00	4.40	0.45	0.66	0.626	(0.60,0.65)	0.652	(0.62,0.69)	0.262
	3-5	1031	606		9.35	5.29	0.64	0.80	0.584	(0.55,0.61)	0.528	(0.49,0.57)	0.025
	6-8	946	620		8.42	5.22	0.59	0.88	0.562	(0.53,0.59)	0.590	(0.55,0.63)	0.273
Family Income	<20K	827	559	0.024	9.87	4.52	0.47	0.71	0.524	(0.49,0.56)	0.534	(0.49,0.58)	0.714
	20-50K	1211	686		9.86	4.77	0.49	0.72	0.525	(0.50,0.55)	0.537	(0.50,0.57)	0.604
	50-100K	597	354		8.61	5.15	0.78	0.81	0.651	(0.61,0.69)	0.664	(0.61,0.71)	0.692
	>100K	592	312		8.21	5.60	0.56	0.90	0.775	(0.74,0.81)	0.736	(0.69,0.79)	0.196
Race	White only	2311	1301	0.080	9.87	5.03	0.52	0.75	0.601	(0.58,0.62)	0.581	(0.55,0.61)	0.226
	African American only	617	418		7.63	4.67	0.67	0.82	0.530	(0.49,0.57)	0.590	(0.54,0.64)	0.060
	Multi-racial including African American	94	64		8.32	4.34	0.57	0.72	0.595	(0.50,0.69)	0.523	(0.40,0.64)	0.369
	Multi-racial excluding African American	56	29		8.54	5.09	0.55	0.87	0.772	(0.66,0.88)	0.733	(0.57,0.89)	0.688
	Other	150	98		8.98	4.71	0.56	0.74	0.675	(0.60,0.75)	0.760	(0.68,0.84)	0.149
Ethnicity	Hispanic/Latino	1438	862	0.721	10.31	4.67	0.43	0.67	0.498	(0.47,0.52)	0.501	(0.47,0.53)	0.910
	Not Hispanic/Latino	1789	1049		8.54	5.13	0.65	0.84	0.671	(0.65,0.69)	0.667	(0.64,0.70)	0.857

* The χ^2 test is to assess whether the distribution of HCS participants with MRR data is similar to the distribution of HCS participants without MRR data. Similarly, the z-test is to assess whether the prevalence of overweight based on the BMI response collected during the HCS household visit differs between participants with and without MRR data. Green shading for p-values below 0.05; peach shading for p-values between 0.05 and 0.10. p-values were not adjusted for multiple comparisons.

** For the sample of participants with valid MRR data, these columns provide (1) the average number of valid BMI measures per participant, (2) the average of how far back in time (in years) the first childhood MRR BMI measure is compared to the date of the household visit, (3) the average of how far back in time (in years) the last childhood MRR BMI measure is compared to the date of the household visit, and (4) the average spacing in time between successive MRR BMI measures.

*** Prevalence of overweight was calculated by comparing observed BMI from the household visit to the 85th percentile of the age and gender adjusted CDC growth curves for each child.

Community programmes and policies

Community programme and policy (CPP) intensity scores for the year prior to the data collection visit had mean and median of 34.9 and 33.6, respectively, and ranged from 10.7 to 81.8, prior to standardization. CPP intensity scores increased over time on average across communities (dark bold line in top panel of Figure 1) and tended to increase over time for most communities (light lines in top panel of Figure 1). Most CPPs were universal, not targeted to particular subgroups at higher risk for obesity (such as African Americans and Hispanics, or those living in low-income communities); no significant differences in CPP intensity scores were observed by community-level sociodemographic characteristics (24,25).

Relationship between body mass index and community-based programs and policy intensity

The parameter that captures the relationship between standardized CPP intensity and childhood BMI (β_1) was estimated as -1.602 kg/m^2 in the minimally adjusted model (p-value = 0.0028) and as -1.398 kg/m^2 (p-value = 0.0077) in the fully adjusted model (Table S1). That is, if a community at the minimum observed CPP intensity score was instead at the maximum observed score (shown as highest and lowest points of individual communities in the light lines in the top panel of Figure 1), it would be predicted to have children who were about 1.6 BMI units smaller, as shown in the dark bold line in the bottom panel of Figure 1.

The longitudinal model also included random-effect community-level intercept and slopes that capture the BMI/CPP relationships. As shown with the light lines in the bottom panel of Figure 1, there is marked variation in these 130 community-specific BMI/CPP relationships with the length of the line along the x-axis, depicting the range of CPP intensity scores within a community. Similar results are provided for the BMI/CPP Relationship with no time lag in Figure S1 and Table S2.

Effect modification

The relationship between BMI and CPP intensity differed significantly as a function of child grade in

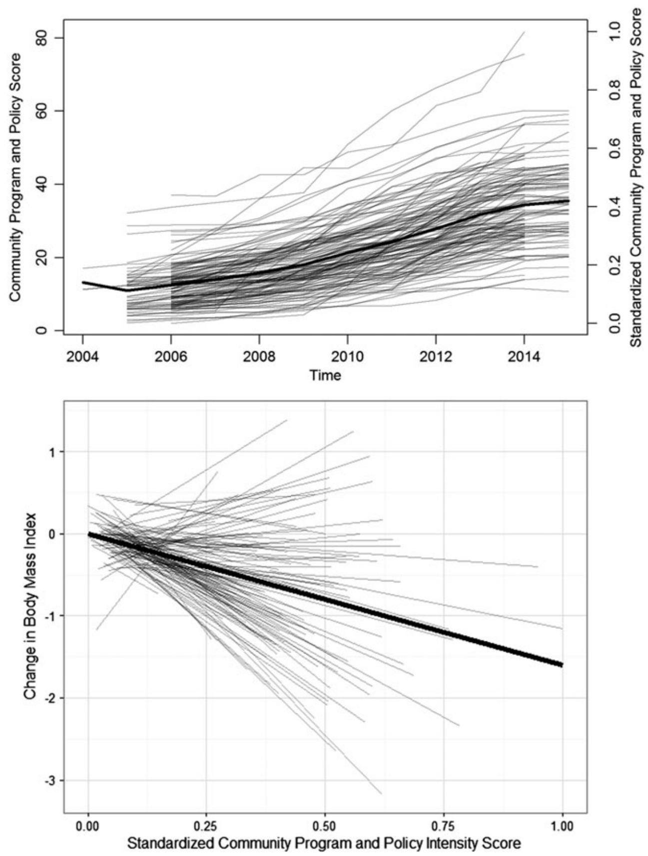

Figure 1 Community programme and policy scores over time across 130 Healthy Communities Study communities (top panel) and relationship between BMI and standardized community programme and policy intensity scores (bottom panel).

school, race, ethnicity, family income and parental education, but did not differ significantly as a function of child gender or parental employment status (Table 2). The relationship between BMI and CPP intensity also differed significantly by community race/ethnicity, but not by region, urbanicity or community income.

The BMI/CPP relationship was significantly different than zero for boys, but not for girls, even though the interaction of CPP intensity and gender was not significant (Table 2). The BMI/CPP relationship was significantly different than zero for children in grades K–2 and 6–8, but not for grades 3–5; for children in suburban communities, but not in urban communities (rural communities were borderline significant); and for children in the Northeast, but not in other regions. Significant BMI/CPP relationships were also found among families with income greater than \$50 000, but not for families with lower income. Similarly, significant BMI/CPP relationships were not observed in high proportion Hispanic or African–American communities compared with other communities, or for Hispanic or African–American children regardless of where they live. Significant BMI/CPP relationships were found for families with the maximum parental education at the high school graduate, Bachelors and Masters levels. Similar effect modification results are provided for the BMI/CPP Relationship with no time lag in Table S3.

Discussion

These data provide evidence of a statistically significant and meaningful (15,26,27) relationship between the intensity of community interventions and childhood obesity, and amplify results observed on cross-sectional analyses of the HCS data (28). Based on the minimally adjusted model, we estimated a reduction of 1.6 kg/m^2 across children in grades K-8 in communities with the most intensive programmes and policies aimed at reducing childhood obesity, compared with communities with the lowest intensity, based on the range of CPP intensity scores observed over a decade in the HCS.

As expected, if a community changed from the minimum to the maximum observed score, the average reduction in BMI was slightly lower (1.4 kg/m^2) after adjusting for key covariates, as some covariates compete with CPP intensity scores for explanatory power, with community characteristics found in the HCS to explain approximately 25% of the variability in observed CPPs (25). Findings suggest that if a community were to expand its combination of programmes and policies promoting physical activity and healthy eating from the mean to the maximum observed intensity score, child BMI would be reduced by 1.1 kg/m^2. To achieve this result, a community might shift from having 5–10 CPPs that mostly provide information and reach less than 5% of children, to having 20+ CPPs that impact policy or modify the food and activity environment while reaching more children.

Multiple temporal versions of the CPP intensity score variable were explored, and scores representing a 2-year cumulative average of CPP intensity, occurring from 4 to 2 years prior to the observed childhood BMI, were most strongly associated with BMI in this longitudinal study. This suggests the importance of substantial and long-term investments in obesity prevention, and the potential delayed effects of those investments.

Our finding that higher CPP intensity scores are associated with lower BMI in a large diverse sample of US children is encouraging; it suggests that community actions to reduce childhood obesity over the past decade have had a beneficial effect. This effect was not uniform, however, and we found that the estimated relationship between CPP intensity and childhood BMI differed significantly among different subpopulations of children. The results of our effect-modification analyses show that CPP intensity had the strongest relationship with BMI in families with higher socioeconomic status (SES) and had the weakest relationship in Hispanic families and in urban communities. It is important to note that these results were not adjusted for multiple comparisons.

Health equity is advanced when community actions to reduce childhood obesity focus on communities with the greatest health disparities. In the HCS, however, there were no statistically significant differences in CPP intensity scores based on community sociodemographic characteristics (25). When coupled with the findings reported here, the HCS data indicate that community efforts, as designed and implemented to date, are not associated with BMI reductions in populations most likely to experience health disparities. One possible explanation is that the types of obesity-reduction CPPs most commonly implemented are not well-tailored to the characteristics and risk factors of groups, such as Hispanic or low SES families (29), in which prevalence of obesity is often the greatest. It is also possible that CPPs have been appropriately designed and targeted for some children, but that their effectiveness is blunted by barriers and/or challenges faced by lower SES families or communities. This fits conceptual models of the mechanisms by which social determinants (30,31) produce health disparities through differential

Table 2 Assessment of potential family and community categorical effect modifiers for the relationship between childhood BMI and CPP (24-month time lag; 24-month cumulative period)

			Minimally Adjusted Model				Fully Adjusted Model			
			CPP Effect Modifiers (Individual Effects)			Type III p-value*	CPP Effect Modifiers (Individual Effects)			Type III p-value*
Covariate	Level	Sample Size	Estimate	SE	p-value*	Interaction	Estimate	SE	p-value*	Interaction
Gender	F	1654	-1.086	0.626	0.083	0.114	-0.858	0.606	0.157	0.106
	M	1573	-2.161	0.649	0.001		-1.954	0.632	0.002	
Grade	K-2	1250	-1.819	0.547	0.001	0.000	-1.556	0.516	0.003	0.000
	3-5	1031	-1.063	0.669	0.112		-0.713	0.643	0.268	
	6-8	946	-3.722	0.814	0.000		-3.238	0.801	0.000	
Race	African American Only	617	-0.249	0.814	0.760	0.014	-0.019	0.796	0.981	0.019
	Multi-Race Incl. Afr. Amer.	94	-0.385	1.540	0.803		-0.484	1.528	0.751	
	Multi-Race Not Incl. Afr. Amer.	56	-3.234	1.808	0.074		-3.095	1.785	0.083	
	Other	150	0.318	1.100	0.773		0.422	1.077	0.695	
	White Only	2311	-2.118	0.566	0.000		-1.874	0.527	0.000	
Ethnicity	Hispanic	1438	-0.551	0.611	0.367	0.002	-0.337	0.592	0.569	0.001
	Not Hispanic	1789	-2.240	0.569	0.000		-2.091	0.548	0.000	
Family Income	<20K	827	-0.127	0.660	0.847	0.000	0.028	0.654	0.966	0.000
	20K-50K	1211	-1.179	0.611	0.054		-1.005	0.602	0.095	
	50K-100K	597	-2.256	0.679	0.001		-2.158	0.676	0.001	
	>100K	592	-3.349	0.736	0.000		-3.320	0.728	0.000	
Max Parent Education	No HS	272	-0.039	0.966	0.968	0.001	0.155	0.975	0.874	0.000
	Some HS	442	-0.306	0.792	0.700		-0.137	0.786	0.862	
	HS	643	-1.572	0.677	0.020		-1.358	0.673	0.044	
	Some College	409	0.095	0.776	0.902		0.303	0.768	0.694	
	Associates	393	-1.237	0.792	0.119		-1.072	0.780	0.169	

Table 2 (Continued)

	Bachelors	518	-2.568	0.711	0.000		-2.492	0.701	0.000	
	Masters and Above	550	-3.263	0.727	0.000		-3.272	0.721	0.000	
Max Parent Employment	Full Time	2363	-1.605	0.553	0.004	0.138	-1.399	0.542	0.010	0.154
	Part Time	308	-1.348	0.916	0.141		-1.096	0.907	0.227	
	Unemployed or On Leave	202	-2.921	1.082	0.007		-2.597	1.078	0.016	
	Retired or Disabled	111	0.840	1.277	0.511		1.015	1.275	0.426	
	Home Student Other	244	-2.300	0.925	0.013		-2.104	0.913	0.021	
Community Region**	Midwest (n_C=26)	628	-1.358	0.998	0.174	0.480	-0.939	0.932	0.313	0.441
	Northeast (n_C=20)	515	-2.915	0.995	0.003		-2.624	0.917	0.004	
	South (n_C=55)	1371	-1.112	0.760	0.143		-0.939	0.707	0.184	
	West (n_C=29)	713	-1.447	0.926	0.118		-1.230	0.875	0.160	
Community Race/Ethnicity**	African American (n_C=34)	659	-1.347	0.902	0.135	0.034	-1.029	0.869	0.236	0.032
	Hispanic (n_C=42)	1329	-0.435	0.730	0.551		-0.276	0.693	0.691	
	Other (n_C=54)	1239	-2.712	0.682	0.000		-2.436	0.653	0.000	
Community Income**	High (n_C=80)	2068	-1.309	0.630	0.038	0.380	-1.095	0.608	0.072	0.374
	Low (n_C=50)	1159	-2.048	0.739	0.006		-1.813	0.709	0.011	
Community Urbanicity**	Rural (n_C=30)	809	-1.886	0.926	0.042	0.175	-1.694	0.879	0.054	0.155
	Suburban (n_C=50)	1285	-2.317	0.710	0.001		-2.061	0.680	0.002	
	Urban (n_C=50)	1133	-0.670	0.716	0.349		-0.451	0.688	0.513	

* Green shading for p-values below 0.05; peach shading for p-values between 0.05 and 0.10. Type III p-values assess whether there are significant differences between the estimated BMI/CPP slopes among the different levels of each categorical effect modifier variable. The individual effect p-values assess whether the BMI/CPP slope for that specific sub-population is significantly different from a value of zero. None of the p-values presented were adjusted for multiple comparisons.

** Community level variables are based on a weighted combination of census tract information (as communities may include >1 tract and/or parts of multiple tracts). African American communities were defined as communities in which >30% of residents were African American. Similarly, Hispanic communities were defined as communities in which >30% of residents were Hispanic. Further detail on the specification of these variables are available in supplementary tables available at the following website: http://dx.doi.org/10.1016/j.amepre.2015.06.021 [17]. The number of communities in the HCS of each type is also indicated (n_C)

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exposures to health-promoting conditions (e.g. safe streets for walking), differential vulnerabilities and capabilities and differential consequences including limited access. Findings are also consistent with others showing a widening gap in disparities in childhood obesity (31), and point to a need to identify and implement comprehensive interventions that effectively reduce childhood obesity and promote equity in conditions that support healthy weight in vulnerable populations (32). Communities with higher existing rates of obesity may require more comprehensive, targeted and sustained approaches to promoting physical activity and healthy nutrition. In the context of other research, identifying reasons for differences in BMI/CPP relationships by urbanicity also merits further study (33).

As a large observational study, the HCS has important strengths and limitations. To assure a large number of diverse communities and children, the HCS oversampled Hispanic and African–American communities and families; this decreased the likelihood that insufficient sample size could explain the lack of significant BMI/CPP relationships in these populations. Use of MRR to document BMI of children over time introduced challenges with inconsistent data quality. The HCS also required use of multiple imputation techniques to overcome challenges posed by missing data. Recruitment of children and key informants from within the same school improved the likelihood that participant children were exposed to the reported school-based CPPs. For logistical reasons, recruitment of children through schools did not employ probability-based sampling (34). Therefore, factors related to non-response could not be assessed, and adjustments for potential selection biases were not pursued. Similarly, documentation of CPPs likely suffered from limitations in recall, records and tenure of some key informants – particularly affecting CPP intensity scores further back in time. We anticipate consistency in this potential bias across HCS communities, perhaps contributing to the general increasing trend of CPP intensity scores over time. Lastly, we note that the results presented represent just one of many different potential computational methods to construct a single overarching longitudinal CPP intensity score (i.e. the method defined in the original HCS protocol) (17). In future work, we will explore longitudinal associations between childhood BMI and a variety of subtype CPP indices. These more specific and tailored CPP indices may yield additional insight into the types of CPPs that are most effective within important subpopulations, leading to strategies that combat disparities in childhood obesity.

Conclusions

Findings from this observational study suggest that the intensity of community programmes and policies – the reach, strategy and duration – makes a meaningful difference in childhood obesity. This fits our understanding of dose-response relationships that childhood BMI (the response) would follow the dose (intensity of community programmes and policies to promote physical activity and healthy nutrition) experienced by a community's children. Because community-wide interventions do not necessarily achieve equal benefits for all children, targeted efforts of sufficient intensity that reach subpopulations, such as racial/ethnic minorities, may also require research and implementation to achieve health equity and assure healthy weight for all our children.

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Conflict of interest statement

The authors have indicated they have no conflicts of interest relevant to this article to disclose.

Author contributions

Mr. Strauss, Dr. Arteaga, Dr. Fawcett, Dr. Ritchie, Dr. Loria, Dr. Frongillo, Dr. Webb and Dr. Pate conceptualized and designed the Healthy Communities Study, developed the field data collection protocols, drafted the initial manuscript and reviewed and revised the manuscript. Mr. Strauss, Mrs. Nagaraja, Dr. Landgraf, Mrs. Weber and Dr. Leifer led and implemented all data management and statistical analyses that supported this manuscript, drafted the initial manuscript and reviewed and revised the manuscript. Dr. John, Ms. Gregoriou and Dr. Sagotov designed and managed the complex implementation of the field data collection programmes across the Healthy Communities Study; provided QA/QC oversight for all study data; drafted the initial manuscript and reviewed and revised the manuscript. Dr. Fawcett, Dr. Collie-Akers and Dr. Schultz designed and implemented the protocol for collecting information from community key-informants to develop the community programme and policy intensity score; provided QA/QC oversight for the data analysis team in calculation of the CPP intensity scores; and helped draft the initial manuscript and reviewed and revised the manuscript. Dr. McIver and Dr. Pate provided QA/QC oversight of the body mass index data, inclusive of data collected directly from child study participants as well as data collected from medical record review; and helped draft the initial manuscript and reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Supporting information

Additional Supporting Information may be found online in the supporting information tab for this article.

Table S1. Parameter Estimates from Longitudinal Model of Childhood BMI as a Function of Community Program and Policy Scores (24-Month Time Lag; 24-Month Cumulative Period); with and without Adjusting for Covariates.
Table S2. Parameter Estimates from Longitudinal Model of Childhood BMI as a Function of Community Program and Policy Scores (No Time Lag); with and without Adjusting for Covariates.
Table S3. Assessment of Potential Family and Community Categorical Effect Modifiers for the Relationship between Childhood BMI and CPP (No Time Lag)

Figure S1. Relationship Between BMI and Standardized Community Program and Policy Intensity Scores (No Time Lag)

