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Examination of community-level interventions addressing early childhood obesity in Los Angeles County

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ABSTRACT

Objective: To help inform decisions regarding the equitable implementation of obesity interventions, we examined whether interventions were equitably reaching the most vulnerable communities, identified communities that received fewer interventions than expected, and estimated the effect of 'dose' of interventions on obesity prevalence.

Methods: We created a database to identify and characterize obesity-related interventions implemented in Los Angeles County from 2005 to 2015 linked to community-level sociodemographic and obesity prevalence data. We ran generalized linear models with a Gamma distribution and log link to determine if interventions were directed toward vulnerable communities and to identify communities that received fewer interventions than expected. We ran fixed-effects models to estimate the association between obesity prevalence and intervention strategy count among preschool-aged children enrolled in the Special Supplemental Nutrition Assistance Program for Women Infants and Children.

Results: We found that interventions targeted vulnerable communities with high poverty rates and percentages of minority residents. The small cluster of communities that received fewer interventions than expected tended to have poor socioeconomic profiles. Communities which received more intervention strategies saw greater declines in obesity prevalence (β = -0.023; 95 % CI: −0.031, −0.016).

Conclusions: It is important to determine if interventions are equitably reaching vulnerable populations as resources to tackle childhood obesity become available. Evaluating the population impact of multiple interventions implemented simultaneously presents methodological challenges in measuring intervention dose and identifying cost-effective strategies. Addressing these challenges must be an important research priority as community-wide interventions involve multiple intervention strategies to reduce health disparities.

1. Introduction

Childhood obesity is a serious public health challenge that starts early in life, in the preschool years (World Health Organization, 2020). In the United States (US), its prevalence among preschool-aged children has vacillated over recent decades, increasing from 7.2 % (1988–1994) to 13.9 % (2003–2004), decreasing to 9.4 % (2013–2014), then increasing again to 13.4 % (2017–2018) (Fryar et al., 2020). The COVID-

Abbreviations: ACS, American Community Surveys; BMI, Body Mass Index; CDC, Centers for Disease Control and Prevention; DMP, Data Mining Project; LAC, Los Angeles County; WIC, Special Supplemental Nutrition Assistance Program for Women Infants and Children; ZCTA, ZIP Code Tabulation Area.

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19 pandemic saw the monthly rate of Body Mass Index (BMI) increase among children of all ages; among 3–5 year-olds, the rate of BMI change during the pandemic increased with weight category, being 6 times greater for children with severe obesity than healthy weight children (Lange et al., 2021).

In the US, children from low-income and racial/ethnic minority families are at especially high risk for obesity (Shrewsbury and Wardle, 2008; Ogden et al., 2018). Interventions to address childhood obesity in these populations have ranged from educational programs that directly target children and/or their parents to place-based "whole-of-neighborhood interventions" that address environmental barriers to healthy eating and active living (Egger and Swinburn, 1997; Minkler, 1999; Wolfenden et al., 2014). Over the last 1.5 decades, prominent public and private funders in this space, including the Centers for Disease Control and Prevention (CDC) and the Robert Wood Johnson Foundation, pledged more than $2 billion to reverse the obesity epidemic through place-based initiatives that emphasized policy, systems, and environmental approaches (Leeman et al., 2015; Centers for Disease Control and Prevention, no date; Robert Wood Johnson Foundation, 2015; Kaiser Permanente, no date; Pastor et al., 2014). While some of these interventions have been evaluated for outcome, to our knowledge, no published studies have examined how public and private sector resources have been distributed across geographic places to support childhood obesity interventions in communities at risk. While epidemiologic clinical indicators, such as prevalence rates, have been used to identify communities at risk, given that the burden of childhood obesity is borne by low-income and racial/ethnic minority communities, and as we strive to achieve health equity, it is important to answer questions such as: *Are relevant interventions equitably reaching the most vulnerable communities, as defined from a social determinants of health perspective, or only those with obesity prevalence above a selected threshold? What factors determine or influence the distribution of interventions?*

In Los Angeles County (LAC), the most populous county in the US (U.S. Census Bureau, no date*a*), several initiatives have been established since 2005 to address childhood obesity in underserved communities (Cheadle et al., 2018; Samuels et al., 2010; Healthy Eating Active Living Cities Campaign, no date; First 5 LA, no date*b*). A sprawling metropolitan region with over 10 million residents, LAC is known for its wealthy communities. However, LAC has one of the highest indices of income inequality in California (Los Angeles Times, no date). In some of its poorest communities, over 40 % of residents have a household income of <$20,000 (Los Angeles Times, no date). A 2007 report showed that childhood obesity prevalence rates varied from 4 % (in affluent Manhattan Beach) to > 40 % in low-income communities (Los Angeles County Department of Public Health, 2007). Public and private initiatives to reduce childhood obesity ensued (Samuels et al., 2010; Healthy Eating Active Living Cities Campaign, no year). Anecdotally, the distribution of funding for obesity reduction initiatives was not well coordinated and some places may have received more programs and policies addressing obesity (higher intervention 'dose') while others may have received fewer programs and policies (lower intervention 'dose') despite having similar (though slightly lower) obesity rates.

We created an inventory of programs and policies (interventions) that had the potential to reduce childhood obesity risk and were implemented in LAC from 2005 to 2015 to: (1) determine whether interventions were directed toward vulnerable communities with high rates of childhood obesity; (2) identify communities that received fewer interventions than expected, but merit prioritization; and (3) estimate the effect of 'dose' of obesity-related interventions on obesity prevalence in preschool-aged children from low-income families. (The construct of 'intervention dose' has been defined in different ways in the literature, but generally includes consideration of intervention strength, fidelity, and reach).

Findings from this study are expected to inform public and private sector decisions regarding the implementation of childhood obesity interventions when the goal is to achieve health equity.

2. Methods

2.1. Overview

We used MySQL v8.0 to create a relational database of obesity-related interventions implemented in LAC from 2005 to 2015 (Samuels et al., 2010; First 5 LA., no date*a*; First 5 LA, no date*c*; Kaiser Permanente, no date; Los Angeles County Department of Public Health, no date). We characterized interventions using a typology developed to classify childhood obesity prevention strategies (Wang et al., 2018), and assigned each intervention to the geographic communities (neighborhoods) it reached, and the year(s) it was delivered. Limited by data availability, we defined neighborhood by ZIP Code. For each year and each ZIP Code, we estimated 'intervention dose' by summing the total number of intervention strategies implemented to provide the 'intervention strategy count'. We calculated ZIP Code-level childhood obesity prevalence for children ages 2–5 years from low-income families residing in LAC, using administrative data for children enrolled in the Special Supplemental Nutrition Assistance Program for Women Infants and Children (WIC), a federal nutrition assistance program serving low-income families (PHFE WIC Program, no date). Using ZIP Code as the unit of analysis, we examined the associations of intervention strategy count with early childhood obesity prevalence and with sociodemographic characteristics.

2.2. Data sources

2.2.1. Intervention data

The created database focused on major obesity-related initiatives in LAC (see Appendix A for examples) (Samuels et al., 2010; First 5 LA, no date*a*; First 5 LA, no date*c*; Kaiser Permanente, no date; Los Angeles County Department of Public Health, no date). Relevant information to characterize the interventions was obtained from multiple sources including reports provided by organizations that funded childhood obesity-related initiatives, websites of both grantor and grantee organizations, interviews with program staff of WIC agencies and the LA County Department of Public Health, and publicly available Tax 990 forms. ZIP Code was the smallest geographic unit for which we were able to extract intervention data.

2.2.2. Obesity data

We calculated ZIP Code-level obesity prevalence for WIC-enrolled children ages 2–5 years residing in LAC using data obtained through the Data Mining Project (DMP) by PHFE WIC (a program of Heluna Health), the largest local agency WIC program in the country (PHFE WIC Program, no date). The DMP has been maintaining administrative records of all WIC participants residing in LAC since 2003; these records provide data on age, ZIP Code of residence, height, and weight. For our study, only the records of children ages 2.0 to 5.0 years with at least one set of height and weight measurements each year were selected. Our study included 258 of the 311 ZIP Codes in LAC; 9 ZIP Codes had no WIC children residing in them, and 44 had less than 30 WIC children and were excluded to protect participant confidentiality. Height and weight were measured by WIC clinic staff who were trained to use a standardized protocol resulting in highly accurate measurements (Crespi et al., 2012).

2.2.3. Sociodemographic data

We obtained sociodemographic data from the Census Bureau's Decennial Census and the American Community Surveys (ACS) at the level of ZIP Code Tabulation Areas (ZCTAs), which are statistical geographic representations of ZIP Codes (U.S. Census Bureau, 2001; U.S. Census Bureau, no date*b*; U.S. Department of Commerce, Economics and Statistics Administration, 2015).

2.3. Study variables

Intervention strategy count was conceptualized as the annual 'intervention dose' a ZIP Code received, and operationalized as the total number of intervention strategies used by all identified projects in a ZIP Code, in a given year. A program may have several projects and each program or project (considered an 'intervention') may use one or more intervention strategies. The intervention strategy count sums the total number of intervention strategies implemented in a community (ZIP Code) in a given year. Fig. 1 illustrates the hierarchical relationships among programs, projects, and intervention strategies, and provides definitions of these terms. The intervention strategies used by each project were classified as macro-level or micro-level using a typology of ten intervention strategies that we previously developed (Wang et al., 2018). Specifically, we defined macro-level strategies as those that do not directly target individuals but affect the larger community, such as a government policy or safe park facilities; and micro-level strategies as those that directly target and serve individuals, such as nutrition education. A description of these strategies is provided in Appendix B. This typology of intervention strategies considered the strength and reach of each strategy from the literature and ratings of reach obtained using the Delphi method (Wang et al., 2018). Information needed to determine the type of intervention strategy used was obtained from grantee information that described a plan of action for achieving specified objectives and producing defined outcomes. It did not include information about fidelity and we assumed that interventions were implemented as described.

Childhood obesity prevalence for each ZIP Code was calculated as the percent of WIC-enrolled children aged 2–5 who have obesity. It was estimated over a 3-year period to obtain stable estimates (e.g. 2003–2005 for the 2005 three-year estimate). Children with a BMI $\geq$ 95th percentile of CDC's growth reference values were categorized as having obesity (Kuczmarski et al., 2002). Children with more than one BMI measure during the 3-year period were categorized as having obesity if they had a BMI $\geq$ 95th percentile for at least two of the three years.

Sociodemographic characteristics of ZIP Codes were defined by three variables: (a) poverty (% residents living below the federal poverty level); (b) education (% residents 25 + years without a high school degree); and (c) racial/ethnic minority composition (% residents who were non-Hispanic Black or Hispanic). For this study, we used data from the 2000 Census, and the ACS 5-year estimates for 2010 to 2015. For 2005 to 2009, we applied linear interpolation to estimate ZIP Code-level sociodemographic values using data from the 2000 Census and the 2010 ACS since Census data are not available for these years.

2.4. Statistical analyses

We calculated yearly minimum, maximum, and mean number of programs, projects, and intervention strategies for 2005 to 2015, and mapped a snapshot of intervention strategy count, early childhood obesity prevalence, poverty levels, education levels, and racial/ethnic composition by ZIP Code for the years 2005, 2010, and 2015.

To determine whether early childhood obesity interventions were being directed toward vulnerable communities, we first regressed annual intervention strategy count on each of the four community-level characteristics (childhood obesity, education, poverty, and minority composition) separately, running four separate Generalized Linear Models (GLMs) with a Gamma distribution and log link (Faraway, 2016) for 2005, 2010, and 2015. We subsequently ran a full GLM regressing intervention strategy count on ZIP Code-level childhood obesity prevalence, poverty, education, and minority composition for 2005, 2010, and 2015.

To identify communities that received fewer interventions than expected, we applied the full GLM model to estimate each community's predicted intervention strategy count based on its obesity prevalence and sociodemographic characteristics for 2005, 2010, and 2015. We subtracted the observed intervention strategy count from the predicted intervention strategy count, and averaged this value over 2005, 2010, and 2015 for each ZIP Code. We used this average difference (between predicted and observed values) to identify ZIP Codes that received fewer interventions than expected.

To estimate the effect of dose of obesity-related interventions on early childhood obesity prevalence, we ran Ordinary Least Squares models with fixed-effects regressing early childhood obesity prevalence on annual intervention strategy count received in the preceding year ($time_{t-1}$). We conducted our analyses sequentially, first constructing an unadjusted model and then adjusting for the following ZIP Code-level time-variant variables: poverty, education, and minority composition (% non-Hispanic Black or Hispanic), and obesity prevalence of the preceding year ($time_{t-1}$). We also included a dummy variable for 2008 and 2009 to take into account the 2008–2009 Great Recession (Morin, 2010) and the 2009 WIC food package change (Food and Nutrition Service (USDA), no date), both of which have been shown to be associated with trends in childhood obesity prevalence rates in the LAC WIC population

Fig. 1. Early Childhood Obesity Systems Science Study (ECOSyS) intervention database classification of interventions addressing obesity.

(Chaparro et al., 2020; Nobari et al., 2018).

$$ObesityPrev_{it} = \alpha_i + \beta_1 InterventionStrategyCount_{i(t-1)} + \beta_2 Poverty_{it} + \beta_3 Education_{it} + \beta_4 Minority_{it} + \beta_5 Obesity_{i(t-1)} + \beta_6 Year2008Dummy_{it} + \beta_7 Year2009Dummy_{it} + \mu_{it}$$

Robust standard errors were calculated using the R package lmtest (Zeileis and Hothorn, 2002).

All statistical analyses were conducted using R version 4.0.3 (R Foundation for Statistical Computer, 2020). All maps were created using ArcGIS 10.5 (ESRI Redlands, CA). The study met the University of California, Los Angeles (UCLA)'s Institutional Review Board guidelines for protection of human subjects concerning safety and privacy.

3. Results

3.1. Interventions

A summary of obesity-related interventions in LAC for 2005 to 2015 is provided in Table 1. In 2005–2007, 307 of 311 ZIP Codes in LAC received obesity-related interventions. By 2008, all ZIP Codes received some form of intervention. In 2005–2008, ZIP Codes had an average intervention strategy count of 6.5, which steadily increased until it peaked at 56.8 in 2013, and then decreased to 47.4 in 2015. On average, more micro-level than macro-level intervention strategies were implemented.

Maps of intervention dose are shown in Fig. 2. Higher intervention dose was observed in underserved areas with higher rates of childhood obesity. For example, intervention dose was high in South LA, one of the poorest areas in LAC, where about half of the residents do not have a high school degree, over 40 % have a household income lower than $20,000, about 90 % are Black or Hispanic, and childhood obesity prevalence was over 15 % in 2005 (PHFE WIC Program, no date; Los Angeles Times, no date). Yearly snapshots of intervention dose reveal an increase between 2005 and 2010, and these increases were largely observed in other underserved areas, such as San Fernando Valley and Antelope Valley— where about 30 % of residents do not have a high school degree, and 40–50 % have a household income of less than $40,000 (Los Angeles Times, no date).

3.2. Early childhood obesity prevalence

Mean prevalence of early childhood obesity steadily increased from 17.8 % in 2005, peaked at 20.3 % in 2009 and 2010, then steadily decreased to 17.8 % in 2015 (Table 2). The highest obesity rates among WIC-enrolled children were in the poorest ZIP Codes (see Supplemental Fig. 1) where obesity rates were continuously above 20 % for 2005 to 2015.

3.3. Sociodemographic characteristics

Mean poverty rates increased from 15.2 % in 2005 to 15.6 % in 2009, decreased to 14 % in 2010, then increased again to 16.2 % in 2015 (Table 2). Over this ten-year period, the percent of adults without a high school diploma decreased from 23.2 % (2005) to 18.8 % (2015), and the percent of residents who were non-Hispanic Black or Hispanic increased from 44.9 % (2005) to 46.6 % (2015). Sociodemographic characteristics varied widely across ZIP Codes. For example, less than 2 % of residents were living below the poverty line in the wealthiest ZIP Codes of LAC compared to almost 80 % of residents in the poorest (Table 2). Similarly, the percent of adults without a high school diploma ranged from a low of 0 % to a high of almost 75 % illustrating large disparities across ZIP Codes (Table 2). While some areas of LAC were predominantly white (over 95 %), other areas were almost entirely Black or Hispanic (over 98 %) (Table 2). The distributions of sociodemographic characteristics across ZIP Codes are shown in Supplemental Fig. 2.

3.4. ZIP Codes where interventions were implemented

To determine whether childhood obesity interventions were directed toward vulnerable communities, we examined associations of childhood obesity prevalence and sociodemographic characteristics with

Table 1
Summary of community-level interventions addressing obesity in Los Angeles County, 2005–2015 (N = 311 communities).

		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number of communities[a] with interventions		307	307	307	311	311	311	311	311	311	311	311
Number of intervention programs[b] per community	*Min*	0	0	0	2	2	2	3	6	8	8	8
	Max	5	5	6	7	8	10	11	14	19	20	19
	Mean	1.24	1.24	1.27	2.3	2.67	3.53	4.70	7.91	10.17	10.23	10.22
Number of intervention projects[c] per community	*Min*	0	0	0	2	2	3	8	15	20	20	16
	Max	5	5	6	7	10	23	32	40	42	42	35
	Mean	1.24	1.24	1.28	2.35	2.82	6.68	11.99	18.67	22.85	23.58	19.98
Number of intervention strategies[d] per community	*Min*	0	0	0	8	8	9	18	34	51	47	37
	Max	20	19	22	24	29	42	61	81	95	96	88
	Mean	6.46	6.45	6.57	8.82	10.82	17.01	26.85	41.88	58.81	56.84	47.37
Number of macro-level[e] intervention strategies per community	*Min*	0	0	0	1	1	2	4	12	17	22	18
	Max	3	2	3	4	6	16	23	31	34	37	30
	Mean	0.05	0.04	0.06	1.07	1.61	4.22	6.47	13.86	18.96	24.21	20.25
Number of micro-level[f] intervention strategies per community	*Min*	0	0	0	7	7	7	14	22	34	25	19
	Max	18	18	19	20	25	33	40	51	67	61	62
	Mean	6.42	6.42	6.51	7.75	9.66	12.79	20.38	28.02	39.85	32.62	27.12

[a]Community defined by ZIP Codes; Los Angeles County has 311 ZIP Codes
[b]A long-term managed portfolio of multiple projects to produce outcomes
[c]A project is short-term and designed to deliver a specified output within a specified time period and location, and may use various intervention strategies
[d]A plan of action that describes a method for achieving project objectives and producing defined outcomes
[e]Intervention strategies that indirectly affect the larger community and obesity-related behaviors and practices
[f]Intervention strategies that directly target a specific population and obesity-related behaviors and practices

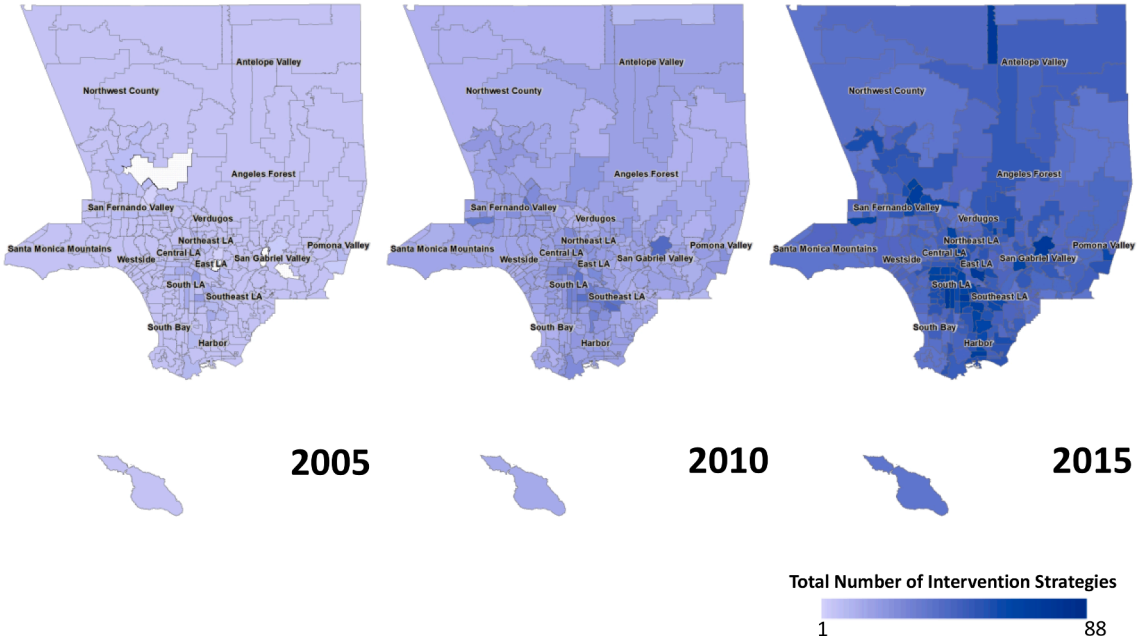

Fig. 2. Distribution of intervention dose[a] across neighborhoods in Los Angeles County, 2005, 2010, and 2015. Neighborhood defined as ZIP Codes; Los Angeles County has 311 ZIP Codes.
[a]Intervention dose operationalized as the total number of intervention strategies targeting obesity implemented for each ZIP Code in a given year; intervention strategy is defined as a plan of action that describes a method for achieving project objectives and producing defined outcomes.

Table 2
Summary of community-level early childhood obesity prevalence and sociodemographic characteristics across communities in Los Angeles County, 2005–2015 (N = 311 communities).

Community[a] characteristics		Year 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Early childhood obesity [%][b]	*Lowest*	5.00	2.44	6.67	7.81	3.33	5.71	5.41	7.32	6.56	5.71	4.43
	Highest	40.98	39.58	35.71	28.06	46.30	41.67	40.28	28.57	28.13	27.81	30.51
	Average	17.79	18.83	19.88	20.15	20.31	20.38	19.98	19.68	18.97	18.26	17.79
Persons below poverty [%]	*Lowest*	1.99	2.15	2.31	2.47	2.63	1.70	1.10	1.60	1.80	1.10	2.50
	Highest	58.05	62.32	66.59	70.87	75.14	54.10	68.90	78.80	72.40	64.10	65.20
	Average	15.24	15.33	15.42	15.51	15.57	13.96	14.33	15.30	15.77	16.30	16.24
Less than high school degree [%]	*Lowest*	0.00	0.00	0.00	0.43	1.61	1.20	0.00	0.00	0.00	0.00	0.00
	Highest	70.17	69.41	69.05	69.02	69.00	64.60	69.60	71.30	72.80	74.20	69.80
	Average	23.15	22.68	22.22	21.75	21.29	20.21	20.02	19.89	19.57	19.31	18.83
Minority [%][c]	*Lowest*	4.47	4.69	4.91	4.81	4.11	4.20	3.20	4.00	2.80	1.70	0.70
	Highest	98.64	98.62	98.64	98.66	98.68	98.60	98.90	98.80	98.70	98.90	98.90
	Average	44.94	45.09	45.25	45.40	45.56	46.12	46.06	46.17	46.33	46.48	46.62

DATA SOURCES: PHFE WIC Data Mining Project (PHFE WIC Program, no date); 2000 Census, 2011-2015 American Community Surveys (U.S. Census Bureau)
[a]Community defined by ZIP Codes for early childhood obesity data and ZIP Code Tabulation Areas (ZCTAs) for sociodemographic data
[b]3 year estimates; obesity status for children 2.0 to 5.0 years enrolled in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) was defined as having a BMI ≥95th percentile of CDC's sex- and age-specific growth reference values; only ZIP Codes with at least 30 WIC children were included (N= 258)
[c]Minority defined as Non-Hispanic Black/African American or Hispanic/Latino

intervention dose (Table 3). In the unadjusted models, higher intervention dose was significantly associated with each community-level characteristic evaluated. Higher obesity prevalence was positively associated with intervention strategy count. In 2005, for each 1 % increase in obesity prevalence, the mean intervention strategy count would be expected to increase by a factor of 1.012 [95 % confidence interval (CI): 1.001, 1.022]. ZIP Codes with higher levels of poverty were more likely to receive more intervention strategies (mean ratio (MR) [95 % CI]: 1.009 [1.006, 1.012] in 2005). As education levels decreased, intervention strategy count tended to increase (MR [95 % CI]: 1.005 [1.003, 1.007] in 2005). Finally, intervention dose tended to be higher in communities with a greater proportion of racial/ethnic minority residents (MR [95 % CI]: 1.003 [1.002, 1.004] in 2005). The significance of these relationships continued to hold in 2010 and 2015. In the full model, intervention dose was significantly associated with poverty and minority composition, but not with obesity rates or education. ZIP Codes with higher poverty rates and percentages of non-Hispanic Black and Hispanic residents received more intervention strategies, and the magnitude of these associations was comparable to those estimated in the unadjusted models.

3.5. *Communities that received fewer interventions than expected*

We identified ZIP Codes that received fewer interventions than would be expected in Fig. 3. These communities had lower income and rates of high school completion than the average community in LAC and higher rates of obesity. All of these communities had high concentrations of Hispanic populations, with the exception of Downtown LA which is highly diverse (35 % Hispanic, 20 % Black, and 20 % Asian) (Los Angeles Times, no date).

Table 3
Generalized linear models (GLMs) with a Gamma distribution and log link: Association of community-level early childhood obesity prevalence and community-level sociodemographic characteristics with intervention dose[a] in Los Angeles County, 2005, 2010, and 2015.

		Gamma GLM model (log link), unadjusted	Gamma GLM model (log link), full model[b]
		Mean Ratios exp(β) [95 % CI]	Mean Ratios exp(β) [95 % CI]
% Early childhood obesity[c]	2005	**1.012 [1.001, 1.022]**	0.997 [0.986, 1.008]
	2010	**1.025 [1.016, 1.034]**	0.994 [0.984, 1.005]
	2015	**1.017 [1.012, 1.022]**	0.997 [0.991, 1.003]
% Persons below poverty	2005	**1.009 [1.006, 1.012]**	**1.011 [1.005, 1.018]**
	2010	**1.017 [1.013, 1.021]**	**1.007 [1.001, 1.014]**
	2015	**1.009 [1.007, 1.011]**	**1.006 [1.003, 1.010]**
% Less than a high school degree	2005	**1.005 [1.003, 1.007]**	0.998 [0.993, 1.004]
	2010	**1.011 [1.009, 1.013]**	1.003 [0.998, 1.009]
	2015	**1.008 [1.007, 1.009]**	0.999 [0.996, 1.002]
% Minority[d]	2005	**1.003 [1.002, 1.004]**	1.001 [0.998, 1.004]
	2010	**1.006 [1.005, 1.007]**	**1.003 [1.001, 1.006]**
	2015	**1.005 [1.004, 1.005]**	**1.004 [1.003, 1.005]**

CI, confidence interval. Statistically significant values are in bold. Community defined as ZIP Codes.

[a] Intervention dose operationalized as the total number of intervention strategies targeting obesity implemented for each ZIP Code in a given year; intervention strategy is defined as a plan of action that describes a method for achieving project objectives and producing defined outcomes.

[b] $InterventionDose = \beta_0 + \beta_1 ObesityPrevalence + \beta_2 Poverty + \beta_3 Education + \beta_4 Minority$

[c] Obesity prevalence averaged over 3 years; obesity status for children 2.0 to 5.0 years enrolled in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) was defined as having a BMI ≥ 95th percentile of CDC's sex- and age-specific growth reference values; only ZIP Codes with at least 30 WIC children were included (N = 258).

[d] Minority defined as Non-Hispanic Black/African American or Hispanic/Latino.

3.6. Obesity-related interventions and obesity prevalence

Higher intervention strategy count was associated with lower obesity prevalence in the *following* year (Table 4). In the unadjusted model, each additional intervention strategy a ZIP Code received was significantly associated with lower obesity prevalence (β = −0.031; 95 % CI: −0.038, −0.025). After adjusting for community sociodemographic characteristics, obesity prevalence in the previous year, the 2008–2009 Great Recession, and the 2009 WIC food package change, this relationship remained and each additional intervention strategy received was significantly associated with lower early childhood obesity prevalence (β = −0.030; 95 % CI: −0.036, −0.024). Results remained consistent in our sensitivity analyses where high-income ZIP Codes (>95th percentile) were removed from all our regression-based analyses.

4. Discussion

We found evidence that interventions implemented in LAC during 2005 to 2015 were directed toward vulnerable communities. Specifically, ZIP Codes with higher obesity prevalence and those with poor socioeconomic profiles tended to receive more intervention strategies. Our findings suggest that rates of poverty and the concentration of racial/ethnic minority residents have influenced the distribution of funds for obesity prevention in LAC, and that both macro- and micro-level interventions (see Appendix A for examples) supported by large-scale initiatives designed to promote child well-being in LAC have had an impact on childhood obesity.

Fig. 3. Neighborhoods that received a lower intervention dose than expected based on neighborhood levels of obesity and sociodemographic characteristics in Los Angeles County between 2005 and 2015. Neighborhoods were identified by comparing neighborhoods' observed intervention dose with its predicted intervention dose based on neighborhood level of obesity prevalence and sociodemographic characteristics and the model: $InterventionDose = \beta_0 + \beta_1 ObesityPrevalence + \beta_2 Poverty + \beta_3 Education + \beta_4 Minority$.

Table 4
Fixed-effects models of the association between community-level intervention dose[a] and early childhood obesity prevalence in Los Angeles County, 2005–2015.

	Fixed-effects model, unadjusted	Fixed-effects model, adjusted[b]
	β [95 % CI]	β [95 % CI]
Intervention $dose_{t-1}$	**−0.031 [-0.038, −0.025]**	**−0.030 [-0.036, −0.024]**

CI, confidence interval. Statistically significant values are in bold. Community defined as ZIP Codes.

[a] Intervention dose operationalized as the total number of intervention strategies targeting obesity implemented for each ZIP Code in a given year; intervention strategy is defined as a plan of action that describes a method for achieving project objectives and producing defined outcomes.

[b] $ObesityPrev_{it} = \alpha_i + \beta_1 InterventionDose_{i(t-1)} + \beta_2 Poverty_{it} + \beta_3 Education_{it} + \beta_4 Minority_{it} + \beta_5 Obesity_{i(t-1)} + \beta_6 Year2008Dummy_{it} + \beta_7 Year2009Dummy_{it} + \mu_{it}$

While we found that major initiatives generally targeted vulnerable communities, we also identified a small cluster of ZIP Codes that received fewer interventions than expected. About half of these had > 85 % racial/ethnic minority populations, high poverty rates, and low rates of high school completion. Childhood obesity rates in these ZIP Codes were high, averaging about 20 %. This finding underscores the importance of coordinated efforts to distribute limited resources *efficiently, effectively, and equitably*. Indeed, obesity prevalence rates in this cluster of ZIP Codes generally decreased more slowly or did not decrease, compared to ZIP Codes that received the expected dose of

interventions (data not shown). This observation is supported by our fixed effects models, which showed that higher intervention dose was associated with lower obesity prevalence in the following year.

Different approaches to interventions targeting population health have been proposed. Lalonde's "high-risk" approach suggests that individuals at high risk for a disease should be targeted so as to maximize health (Lalonde, 1974). Rose's "population" approach aims to target the entire population regardless of risk factor, disease status, or need (Rose, 1992). While this has been shown to be more effective in reducing population-level disease risk, Frohlich and Potvin argue that health disparities may be exacerbated by such an intervention approach, and propose the "vulnerable population" approach to target under-resourced populations, rather than the entire population (Frohlich and Potvin, 2008). Our findings contribute to the emerging evidence showing that community-based prevention approaches targeting under-resourced communities (rather than only high-risk individuals or entire populations) and designed to modify both individual behaviors and the environmental contexts in which they develop, have the potential to reduce early childhood obesity rates— supporting Frohlich and Potvin's approach and the need for multi-level interventions. Since low household income is a risk factor for early childhood obesity in the US (Ogden et al., 2010), interventions that target vulnerable communities may help reduce overall rates of obesity among preschool-aged children in the US.

4.1. Strengths and limitations

Creating an intervention database that used a typology to classify programs and projects facilitated the concept of *intervention strategy count*, allowing us to quantify exposure of a community to various intervention strategies implemented simultaneously by programs and projects. Our finding of a negative relationship between intervention strategy count and subsequent obesity prevalence at the ZIP Code level contributes to the mixed evidence on the impact of place-based interventions on obesity risk (Wolfenden et al., 2014; Leeman et al., 2015; Boelsen-Robinson et al., 2015; Ewart-Pierce et al., 2016). In another study, using this same intervention database, we showed that both macro- and micro-level intervention strategies may be important in place-based interventions (Nianogo et al., 2022). In particular, we observed that two intervention strategies, namely, home visitations and food business practices (e.g. organizational food procurement policies), and macro- and micro-level strategies targeting breastfeeding, a protective factor for childhood obesity (Bartok and Ventura, 2009), were moderately effective in reducing obesity risk among WIC-enrolled children aged 2–5.

Our study has several limitations. First, our intervention database is not comprehensive of all obesity-related interventions that took place in LAC. It focused on interventions implemented by major public and private funders tackling early childhood obesity in LAC, and by WIC clinics in regions of LAC where the majority of WIC families reside. Second, while the use of intervention strategy count to assess intervention dose allows for the quantification of exposure to various strategies, it does not directly consider the strength, reach, or fidelity of a strategy. However, it is notable that the Healthy Communities Study, which assessed program 'intensity', found it was the count of physical activity programs that was related to consumption of fewer energy-dense foods and whole grains (Ritchie et al., 2018). Third, we were unable to consider the length of time different strategies take to produce an effect. Fourth, intervention data were available only at the ZIP Code level, which are relatively large geographic spaces and consequentially more likely to display heterogeneous effects (Krieger et al., 2003).

5. Conclusion

Considerable resources have been expended to tackle childhood obesity, and it is important to determine if interventions are equitably reaching vulnerable populations. We found that interventions implemented in LAC (from 2005 to 2015) targeted vulnerable communities, and areas which received more intervention strategies (macro- and micro-level) saw greater declines in obesity prevalence. However, a small cluster of communities received fewer interventions than expected suggesting a need for evaluating the impact of large-scale initiatives on such communities. Further, evaluating the population impact of multiple interventions implemented simultaneously presents methodological challenges in measuring intervention dose and identifying cost-effective strategies. Addressing these challenges must be an important research priority as funders continue to support community-wide interventions involving multiple intervention strategies to reduce health disparities.

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CRediT authorship contribution statement

Shelley Jung: Writing – review & editing, Writing – original draft, Conceptualization, Formal analysis, Methodology. **Michael Prelip:** Writing – review & editing, Project administration, Resources, Funding acquisition, Methodology. **Hayley Roper-Fingerhut:** Investigation, Writing – review & editing. **Tony Kuo:** Funding acquisition, Resources, Writing – review & editing, Conceptualization. **Paul Simon:** Writing – review & editing, Funding acquisition. **Shannon E. Whaley:** Resources, Writing – review & editing, Conceptualization, Funding acquisition. **May C. Wang:** Writing – original draft, Writing – review & editing, Methodology, Project administration, Resources, Conceptualization, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A:. Examples interventions supported by initiatives to address childhood obesity in Los Angeles County, 2005–2015

Best Start Communities (BSC) and First 5 LA Welcome Baby (First 5 LA, no date*b*; First 5 LA, no date*c*): First 5 LA, which was created in 2010 with tobacco tax revenues, heavily invested in 14 Best Start Communities (BSC) in LAC to promote early childhood development and health. BSCs are

racially/ethnically diverse communities that face critical issues such as poverty and low school performance, but also have a strong network of local leaders and organizations dedicated to their communities. Through these partnerships, First 5 LA invested in programs using multiple intervention strategies to strengthen both the capacity of families to raise healthy children and the capacity of communities to support healthy families. An example is The Welcome Baby Program, which involved the implementation of six strategies at the macro and micro levels to promote breastfeeding, observed to reduce childhood obesity risk. The Welcome Baby Program provides an opportunity for parents to learn about their new role as mom or dad, early child development, and obtaining assistance on issues such as basic health care, insurance coverage, nutrition, breastfeeding, family violence, maternal depression, or improving home safety. The program is free, community-wide, voluntary, and universally provides hospital and home-based intervention for pregnant and postpartum women. The primary objective is to work with families to maximize the health, safety and security of the baby and parent–child relationship and to facilitate access to support and services when needed. Offered to all families regardless of income status, potential challenges or risk, Welcome Baby includes prenatal and postpartum home-based visits, as well as a hospital visit at the time of the child's birth.

Los Angeles Department of Public Health (LADPH)— Communities Putting Prevention to Work Initiative (CPPW) (Los Angeles County Department of Public Health, no year): Communities Putting Prevention to Work (CPPW) is an initiative designed to make healthy choices easier by promoting environmental changes at the local level. Through CPPW funding, which was awarded in February and September 2010, a total of 50 communities worked to prevent obesity and/or tobacco use— the two leading preventable causes of death and disability. For example, all LAC hospital food-service providers began to offer healthy food and beverage options. LAC worked with partners in communities with the highest levels of childhood obesity to educate residents about healthy choices through a media campaign focused on unhealthy drinks, supported LAC Public Schools' plans to improve cafeteria menus to include healthier options and promote physical education, encouraged county hospitals and employers to adopt and implement breast-feeding policies, and provided education to help cities comply with the new Complete Streets state law.

Kaiser Permanente's Healthy Eating Active Living (HEAL) Initiative (Healthy Eating Active Living Cities Campaign, no date; Kaiser Permanente, no date): The Healthy Eating Active Living (HEAL) Zones are a Kaiser Permanente program designed to help make healthy choices more accessible to people in underserved communities. The initiative was a major community engagement effort that worked to bring on board all sectors of each 'zone'— from schools and local governments to faith groups and businesses, as well as hospitals and health clinics, residents, and more. The goal was to reduce calorie intake, increase consumption of healthy foods and beverages, and increase physical activity for upwards of 200,000 residents living in those targeted areas.

Appendix B

Classification of intervention strategies (modified from (Wang et al., 2018)).

MACRO-LEVEL INTERVENTION STRATEGIES[1]
1) Government policies: National, state or local policies (e.g., principles, rules, guidelines, legislation) that aim to influence the accessibility of healthy and unhealthy foods, increase opportunities for physical activity, improve healthcare access, or promote breastfeeding. *Examples:* Food subsidies to support locally grown foods; food taxes on sugar-sweetened beverages; zoning laws to limit fast food operations; regulation of food marketing practices targeting children; tax breaks to businesses that provide on-site recreational facilities for exercise; health insurance for low-income children; longer maternity leave
2) Public institutional policies: Policies by public institutions such as county governments, school districts, Head Start childcare programs, and healthcare facilities that aim to increase the accessibility of healthy (vs. unhealthy) foods, increase opportunities for physical activity, or promote breastfeeding. *Examples:* Nutritional guidelines for food procurement and foods served; mandatory physical education for students; schools allowing their facilities to be used by residents during weekends (joint-use agreements); baby friendly hospital policies
3) Infrastructure investments: Efforts to change the physical environment to promote healthy eating and active living. *Examples:* Walkable neighborhoods; parks; establishment of healthy food venues (e.g., farmers' markets, supermarkets)
4) Business Practices: Practices by the private sector that influence consumer choice and decision- making. *Examples:* Product placement in a grocery store; restaurant procurement of locally grown foods; menu changes; menu-labeling
MICRO-LEVEL INTERVENTION STRATEGIES[2]
1) Group education: An intervention that involves imparting knowledge and/or skills to a group of individuals, including breastfeeding workshops; nutrition education, exercise and parenting classes; and cooking demonstrations.
2) Counseling: Interactions with the child and/or child's parent/caregiver by a trained counselor or para- professional with the goal of changing food consumption patterns of the child, parenting style, or parenting practices.
3) Health communication & social marketing: The use of communications strategies, consumer research, and/or marketing principles to promote health by influencing individual decisions that affect health.
4) Home visitation: A program that primarily delivers family-oriented services through home- visiting and may address parenting practices and child feeding practices.
5) Screening & referral: A program that screens for suboptimal growth (e.g., overweight/obesity) and/or inadequate nutrition, and refers the child to appropriate programs such as WIC.
6) Staff training*: Staff training, which was originally grouped together with the micro-level strategy 'group education' for which the training was provided.

[1]Strategies that indirectly affect the larger community and obesity-related behaviors and practices.

[2]Strategies that directly target a specific population and obesity-related behaviors and practices.

*Originally grouped together with group education.

Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2024.102708.

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