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Assessing impacts of redeveloping public housing communities on obesity in low-income minority residents: Rationale, study design, and baseline data from the Watts Neighborhood Health Study

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ABSTRACT

Introduction: Obesogenic built- and social-environments in low-income and minority communities are often blamed for the higher rates of obesity in this population, but existing evidence is based largely on observational studies. This study leverages a natural experiment created by the redevelopment of a public housing community to examine the impact of major improvements to the housing, built, and social environments on obesity among residents.

Methods/design: The study design is a natural experiment where residents from the redeveloped community (treatment group) will be compared to those from a similar community (control group) in terms of their pre/post changes in primary outcomes using annual longitudinal data on a cohort of residents. Quasi-experimental variation in the timing of exposure to various redevelopment components within the treated community will be further leveraged within a stepped-wedge research design to assess the impact of the redevelopment components. Primary outcome measures include body mass index, overweight, and obese status.

Results: A cohort of 868 adults and 704 children (ages 2–17 years) was recruited during 2018–2019 with up to two waves of baseline data. At baseline, the prevalence of obesity (overweight or obesity) was 57.2% (81.3%) in adults and 33.1% (52.4%) among children, with no significant differences by treatment status. No differential trends in primary outcomes were observed by treatment status during the two years of baseline.

Discussion: This natural experiment study offers a unique opportunity to assess whether improvements to housing, built, and social environment in low-income minority communities can lead to reductions in obesity.

1. Introduction

Obesity remains a major public health concern in the U.S. population and places a disproportionately high burden on minority and low-income populations. In 2017–2018, an estimated 42.4% of U.S. adults aged 20 and over were obese [1]. The prevalence of obesity is highest among non-Hispanic black (49.6%) and Hispanic (44.8%) adults relative to non-Hispanic white (42.2%) adults.

A growing sense that individual-based determinants alone cannot explain the epidemic increase in obesity and its associated racial-ethnic disparities has propelled interest in the role of the built- and social-environment in influencing obesity. Neighborhood built and social environment characteristics such as walkability, exercise opportunities, green space, food outlets, social cohesion, and crime have been shown to be correlated with obesogenic behaviors and obesity [2]. Moreover, studies show that minority and low-income populations, who are more likely to be overweight or obese, are also more likely to live in worse environments with respect to healthy food access, places to exercise, neighborhood aesthetics, and traffic or crime-related safety [3]. But, a critical gap in the evidence base is whether the observed associations between the built- and social-environment and obesity are causal and whether improving these environments in disadvantaged communities can reduce disparities [4–7]. The existing evidence is based largely on observational studies, which can at best establish correlations due to self-selection of individuals into neighborhoods. Randomized controlled studies are largely infeasible for studying causal effects of the types of large-scale, multicomponent community improvements that may be needed for meaningful and sustained reductions in health dis-

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parities. Natural experiments can fill that void and provide the necessary evidence for understanding how improvements in community built- and social-environments can reduce health disparities. However, existing evidence from natural experiments and quasi-experimental studies is sparse [8] and there is a critical need for such studies to build a strong evidence base [9,10].

The Watts Neighborhood Health Study seeks to address this open and critical question by studying a natural experiment that will significantly improve the built- and social-environment, as well as housing quality, in a low-income urban public housing community. The primary goal of the study is to examine the effects of the redevelopment on residents' Body Mass Index (BMI) and obesity. In addition, the study has several secondary aims. First, it seeks to disentangle the effects of the three main components of the redevelopment – built environment, social environment, and new housing – on BMI and obesity. Second, it will examine changes over time in residents' intermediate outcomes including physical activity, dietary intake, physical and social interaction with the new environments, and individual- and social-factors such as perceptions of the environment, self-efficacy, social norms, social support, community cohesion, and psychological well-being. This will allow us to look inside the "black box" and shed light on why, or why didn't, the redevelopment improve residents' BMI and obesity outcomes. Finally, the study will explore the moderating effects of residents' sex, race-ethnicity, and age. In this paper, we describe the study's rationale, design, and protocols, and provide baseline data.

2. Design and methods

2.1. Study overview

The study design is a natural experiment where the Jordan Downs (JD) public housing community in Los Angeles (LA) will receive a multicomponent "intervention" consisting of major improvements to housing and to the built and social environments. The intervention components will roll out in phases over a 10-year period where clusters of residents will get exposed to different combinations of the intervention components, allowing us to disentangle their independent effects. A cohort of 609 adults and 466 children has been recruited from JD and will be followed longitudinally through the redevelopment phases. In addition, a control group of 259 adults and 238 children has been recruited from two similar public housing developments in South LA that will not receive any of the redevelopment components; this group will also be followed longitudinally. The current study funding will allow annual data collection from the treatment and control group residents over a 4-year period. Additional funding will be sought to continue following this cohort in later years. The study was approved by the University of Southern California's Institutional Review Board.

2.2. Redevelopment components

The JD redevelopment has three broad components – [1] New housing (H): all current residents from 666 obsolete, low-quality units will be relocated to new, high-quality, and aesthetically appealing housing [2]; Social environment (SE): the addition of 700 mixed-income housing units will bring in new residents who will occupy units that are interspersed with units given to the original residents, thereby altering the socioeconomic composition of the community and increasing interaction with new residents; and [3] Built environment (BE): built environment changes will include a new community center and gymnasium, 120,000 sq. ft. of retail space including a new supermarket, 9 acres of green space, bike lanes and pedestrian friendly streets and blocks, community gardens, and several safety and aesthetic improvements to the community.

2.3. Natural experiment

A key reason why Jordan Downs was selected for redevelopment over other public housing sites in LA was because there was a vacant 21-acre former-industrial parcel of land that was owned by the city and located at the center of the JD community, which provided additional land for the redevelopment. This allowed the developers to use a "build first" approach in which current JD residents can continue to live in existing housing until their new housing is ready for them. This approach effectively eliminates the need for displacing residents during the course of the redevelopment. Importantly, it also creates an opportunity for a strong longitudinal study design by minimizing the confounding factors induced by displacement and attrition rates over time. This is a major advantage over other public housing redevelopment projects (e.g. HOPE VI) that had to relocate residents to other communities for several years because of absence of build-first options, which consequently led to the vast majority of residents not returning or being lost to follow-up [11].

In addition, the build first approach also implies that relocation and redevelopment will occur in phases over 6–10 years. This creates exogenous variation in residents' exposure to different redevelopment components, which will allow us to disentangle effects of the redevelopment components on residents BMI and obesity outcomes. Remaining on the same site throughout the process also ensures that the residents are offered the same treatment components (e.g., access to the same supermarket or community center), although their timing of exposure to some components might vary, for instance, due to different move-in schedule for new housing. This is critical to causal inference, supporting the Stable Unit Treatment Value Assumption (SUTVA) that serves as the fundamental basis for randomized control trial designs [12]. SUTVA emphasizes a single version of each treatment level or component and that one unit's access (or lack of access) to the treatment is not interfered with another unit's access (or lack of access).

Table 1 illustrates the general design of the natural experiment. The treatment group (current JD public housing residents) can be divided into multiple clusters, say T1-T5, based on the timing of their relocation to new housing. The clusters of residents who move in various phases of the redevelopment is determined based on a demolition-and-construction timeline prepared by the developers to minimize resident displacement. The site is divided into sections consisting of clusters of buildings that will be demolished in each phase. All residents from those buildings will be relocated to their new units before their buildings are demolished. New housing is constructed in place of the demolished old buildings and residents living in the next phase of buildings to be demolished will be relocated to this new housing. This process of construction, relocation, and demolition is repeated throughout the course of the redevelopment. This timeline, to our knowledge, is unrelated to the outcomes of interest in our study. Period 0 represents the baseline when neither treatment nor control residents are exposed to the redevelopment. The built environment (BE) improvements will begin in period 1 and should impact all treatment clusters throughout the study period since they occur in common areas. The changing social environment (SE) resulting from the influx of new mixed-income residents will initially affect only those treatment clusters who have moved into new housing, but will subsequently affects all clusters as the number of new residents increases. In contrast, the housing component (H) will only affect residents who move to new units. In period 1, the first cluster of residents selected for relocation (T1) will be exposed to all three components of the redevelopment, whereas the remaining groups (T2-T5) will only be exposed to the BE component. In each subsequent period, an additional treatment cluster will move into new housing and therefore receive all three components from that point forward, and so on. Finally, a pure control group of residents will further allow us to control for time trends in outcomes in that community in the absence of the redevelopment

Table 1
Illustration of study design.

	Cluster	Time Period					
		0	1	2	3	4	5
Treatment Group (JD Residents)	T1	–	BE + SE + H	BE + SE + H	BE + SE + H	BE + SE + H	BE + SE + H
	T2	–	BE	BE + SE + H	BE + SE + H	BE + SE + H	BE + SE + H
	T3	–	BE	BE	BE + SE + H	BE + SE + H	BE + SE + H
	T4	–	BE	BE	BE + SE	BE + SE + H	BE + SE + H
	T5	–	BE	BE	BE + SE	BE + SE	BE + SE + H
Control Group	C	–	–	–	–	–	–

Notes: BE = built environment (e.g. retail, park space, and gymnasium); SE = Social environment (e.g. # of mixed-income neighbors); H = new housing. Each cell represents the redevelopment component(s) that a particular treatment group cluster (captured by the row) was exposed to in a specific time period (captured by the column). So, for e.g., BE + SE + H implies that individuals in that cluster and time period were exposed to all three redevelopment components, where BE only implies that individuals in that cluster and time period were exposed to only the BE redevelopment component. Time Period 0 represents baseline, i.e. prior to any redevelopment. Control group residents are not exposed to any redevelopment components.

and assess whether the JD redevelopment, as a whole, affected residents' BMI and obesity outcomes differentially compared to those in the control group.

2.4. *Study hypotheses*

Fig. 1 shows the conceptual framework for the study. We hypothesize that the redevelopment will impact residents' BMI and obesity outcomes via three primary channels – [1] increased opportunities for healthy behaviors [2], individual-level mediators, and [3] social mediators. The redevelopment will directly improve BMI and obesity outcomes by increasing opportunities for healthy eating and physical activity via built environment improvements in the community. Furthermore, the relocation to new and improved housing may promote healthy diet and activity behaviors directly by creating more opportunity for healthy behaviors. For example, improved indoor space and well-ventilated kitchens, combined with a clean water delivery system may encourage residents to cook more meals at home – an often healthier alternative to eating out – while more spacious apartments may provide room for exercise equipment.

In addition, we hypothesize that the redevelopment will impact BMI and obesity outcomes indirectly through individual-level and social mediators. The move to new, high-quality housing and a revitalized community can induce residents to engage in healthy behaviors by improving perceptions of built environment (e.g. safety, accessibility, awareness of opportunities), increasing self-efficacy, and improving sleep quality and psychological well-being (e.g. reduced stress, improved mental health and life satisfaction). The inflow of new mixed-income housing neighbors will alter the social environment by changing the community's socioeconomic composition, residents' social networks, and social norms and social support for healthy lifestyles in the community. The revitalized built- and social-environment may increase social cohesion and sense of community among residents by providing safe places to gather.

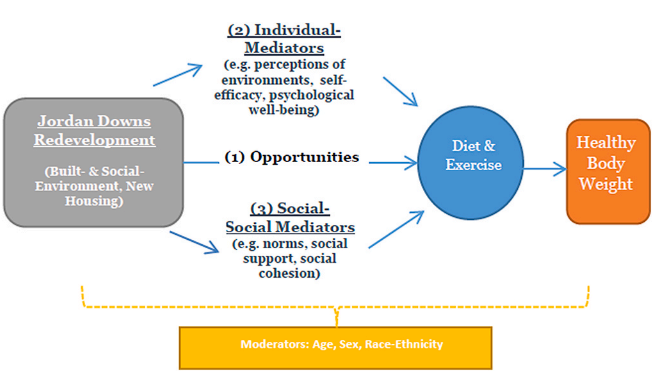

Fig. 1. Conceptual framework.

2.5. *Research setting*

Jordan Downs is a 49-acre public housing development built in the mid-1940s as transitional housing for WWII veterans and converted into public housing in the early 1950s. It is located in the predominantly Latinx and Black community of Watts in Los Angeles, California. Watts is also home to three other public housing developments that serve low-income families – Nickerson Gardens, Imperial Courts, and Gonzague Village. In 2018, Jordan Downs included a total of 666 occupied housing units, with 2282 residents, whereas the control sites, Nickerson Gardens and Imperial Courts, included a total of 1517 occupied housing-units that housed 4609 residents. According to demographic data published by the Housing Authority [13], JD and the control sites are very similar in terms of poverty rates (64%–69%), average gross monthly income per family ($1456-$1656), residents' age distribution (46%–48% < 18 years, 29%–31% 18–40 years, 16%–18% 41–60 years, and 5%–6% above 60 years), and the percentage of adults who are female (68%–74%). All three sites have predominantly Hispanic and Black residents (≥98%), although the Hispanic percentage is higher in JD (67% in JD, 57% in Imperial Courts, 61% in Nickerson Gardens). Moreover, being in Watts, all three similarly lack opportunities for healthy eating and physical activity in the community, according to a Residents' Needs Assessment conducted by the Watts Community Studio [14].

2.6. *Eligibility, recruitment, and retention*

All adults and children ages 2 years and older living at Jordan Downs, and a subsample of adults and children at Imperial Courts and Nickerson Gardens, who speak English or Spanish were eligible for participation in the study. Sample recruitment relied on a multi-pronged approach, including multiple rounds of distribution of flyers and letters to homes, promotion at onsite events (e.g., thanksgiving turkey giveaway, holiday toy distribution), and door-to-door visits. We also partnered with Community Coaches (residents hired by the Housing Authority for community outreach) or other resident leaders at each site to assist with flyer distribution and door-to-door recruitment. As a result of our presence in community spaces, we also benefited from word of mouth among neighbors, and some participants were recruited as "walk-ins." Since all housing units in JD were invited to participate, these recruitment efforts were more intensive at JD than at the control sites and resulted in the recruitment of members from 62% of JD housing units. At the control sites, enrollment was conducted on a first-come-first-serve basis and was closed when the target sample size for the control group was achieved. The different recruitment approaches for JD and the control sites were necessary in order to achieve the desired sample sizes for the study design. Potential concerns about differences in the JD and control samples (e.g. control sample may be motivated since it was first-come-first-serve) may be addressed in the analysis stage by subsetting JD sample to early participants to make them more comparable to control sample. Also, propensity score weighting can be used to match the two groups.

2.7. Participant data collection timeline and procedures

Households were recruited between May 2018 and Dec 2019. This time period also served as the "baseline" since no major redevelopment components were completed during that period due to delays in the construction timeline. Since the study design involves annual data collection from participants, those recruited in 2018 participated in two waves of baseline data collection (Wave 1 and Wave 2), whereas additional family members from participating households who were recruited after May 2019 participated in only one wave of baseline data collection (Wave 2).

During baseline data collection, adults and children were assessed at either an on-site community space or the participant's home. In wave 1, data collection occurred over two in-person interviews with the household, approximately 1 week apart. During the first interview, adults and children (9–17 years old) participated in an interviewer-administered survey about obesity-related behaviors and risk factors. These participants also completed a 24-h dietary recall and participated in anthropometric assessments. They were also asked to wear an accelerometer for the seven days between interviews. In wave 2, adults and children (9–17 years old) participated in in-person surveys and anthropometric assessments. Children ages 2–8 years old participated in anthropometric assessments in both waves.

Surveys typically took 45 min to 1 h for adults and 30–45 min for children. Participants were provided with cue cards as visual aids for response options and compensated for their participation in each wave. Similar data collection will continue in future waves, conducted annually.

2.8. Measures

Table 2 presents a summary of the measures collected at baseline (waves 1 and 2) and while the redevelopment is in progress (waves 3, ongoing, and 4, planned).

BMI, Overweight, and Obesity: The primary outcomes for the study are participants' body mass index (BMI) and overweight or obese status. These variables were constructed using data that was collected via anthropometric assessments conducted by trained staff. The assessment included measurement of height to the nearest 0.1 cm, weight to the nearest 0.1 kg, body fat percentage to the nearest 0.1%, and waist circumference to the nearest 0.1 cm. Height was conducted on a stadiometer (Charder HM200P Portstad Portable Stadiometer, Charder), waist circumference was measured using a tape measure, and weight and body fat percentage was obtained from a Tanita UM-081 digital scale. Trained interviewers completed each measurement two times. A third measurement was required if the difference between the measurements was greater than 0.5 cm, 0.2 kg, 0.5%, and 1 cm for height, weight, body fat, and waist circumference, respectively. BMI was measured as weight in Kilograms divided by height in meters squared. Adults were classified as obese (overweight) if their BMI was ≥ 30 ($25 \leq \text{BMI} < 30$). For children ages 2–17 years, BMI z-score for age and sex was computed using the 2000 CDC growth chart. Additional measures of adiposity, such as abdominal obesity (based on waist circumference) [15,16] and percent body fat, will also be created.

Dietary Intake: Dietary intake is an intermediate outcome and is assessed in multiple ways. In wave 1, dietary intake was assessed twice, one week apart, using the National Cancer Institute's (NCI) Automated Self-Administered 24-h Dietary Assessment Tool (ASA24®). We adapted the ASA24®, an online questionnaire that allows participants to detail all food and drink consumed the prior day, with details about what exactly they ate, what time they ate, and where they ate, for interviewer-assisted administration. Two interviewer-assisted 24-h dietary recalls were conducted with adults and children (9–17 years old) using the ASA24® 24-h recall tool [17]. The tool guides respondents through multiple steps of recalls including a meal-based list, gap review, detailed pass, forgotten foods, and a final review. The recalls were used to construct dietary intake variables including, but not limited to, fruits and vegetables (cups/day), dairy (cups/day), whole grains (oz/day), total calories (per day), and the 2015 Healthy Eating Index score [18]. In addition, we also administered a single-item measure for diet quality. Adult participants were asked: "In general, how healthy is your diet? Would you say it is … Excellent, Very good, Good, Fair, Poor."

In wave 2, we chose to replace the wave 1 measures with a different dietary assessment since the 24-h dietary recalls appeared burdensome, were subject to recall problems (e.g. respondents, especially children, not knowing what was in the meals when they ate out) and indicated some reactivity (e.g. respondents reporting very few meals or snacks during the reference period, perhaps to reduce participation burden). Adult participants completed NCI's Dietary Screener Questionnaire (DSQ) to assess consumption frequency of key food groups [19]. The screener includes 26 items. Respondents were asked how often each item was consumed in the past 30 days (never, 1 time, 2–3 times, 1 time per week, 2 times per week, 3–4 times per week, 5–6 times per week, 1 time per day, 2 or more times per day). Responses to the screener were used to construct dietary intake variables for various food groups - including, but not limited to, fruits and vegetables (cups per day), dairy (cups per day), and whole grains (ounces per day) following the data processing and scoring procedures developed for the National Health and Nutrition Examination Survey. Child participants (9–17 years old) completed the Beverage and Snack Questionnaire (BSQ) [20] that asked about the consumption frequency of 19 items, including beverages such as soft drinks, energy drinks, juice, and milk, and salty and sweet snacks [20]. Responses were used to construct measures of salty snack, sweets, and soda consumption (times per day).

Physical Activity: Physical activity is an intermediate outcome and was assessed in multiple ways. In wave 1, adults and children (9–17 years old) were asked to wear an Actigraph, Inc. wGT3X-BT accelerometer as a belt for 7 days to collect continuous physical activity data. The device was worn on the participant's right hip, attached to an adjustable belt. Participants were asked to wear the belt at all times except sleeping, bathing, or swimming. Actigraph software was used to identify periods of non-wear (>60 continuous min of zero activity counts) and calculate valid days (≥ 10 h of wear). Participants who did not have at least two valid days of wear were asked to wear the accelerometer again. Accelerometer data was used to compute respondents' minutes per day of moderate-to-vigorous physical activity. In addition, adults also self-reported the amount of physical activity that they did during work and outside of work within the past week in a manner similar to NHANES. The number of days of physical activity, as well as the activity duration on a typical day, were separately collected for moderate and vigorous activity and used to compute minutes per day of total moderate-to-vigorous activity and minutes per day of leisure time moderate-to-vigorous activity. Adults also reported time spent watching TV and playing video games. We constructed a measure of total daily minutes spent on these sedentary activities. Children similarly reported weekly days and the typical daily amount of moderate and vigorous activity, which were used to compute total minutes per day of moderate-to-vigorous activity. They reported how many sports teams they played on and other organized physical activities they participated in during the past year. Children also reported time spent watching TV, playing computer or video games, and going on the internet on weekdays and weekends.

In wave 2, we chose to collect alternate measures of physical activity because accelerometry presented some challenges in the field, in-

Table 2
Data collection for Watts neighborhood health study.

	Constructs/Measures	Source(s)	Respondent Type	Baseline or Pre-Redevelopment		Redevelopment in Progress	
				Wave 1	Wave 2	Wave 3[a]	Wave 4[b]
Primary Outcomes	Body Composition						
	Height, weight, % body fat, waist circumference	Direct assessment by interviewer	Adult and Child	X	X	X[c]	X
	Self-report height and weight	Survey	Adult and Child[d]	X		X	X
Intermediate Outcomes	Dietary Intake						
	24-Hr Dietary Recall	ASA24®	Adult and Child	X			
	Dietary Screener and behaviors	Survey	Adult and Child	X	X	X	X
	Physical Activity (PA)						
	Accelerometry	Direct Assessment with Accelerometer	Adult and Child	X			
	Self-reported PA	Survey	Adult and Child	X	X	X	X
	Self-reported sedentary behaviors	Survey	Adult and Child				
Correlates and Potential Mediators	Psychosocial Risk Factors Related to Diet and PA	Survey					
	Self-Efficacy		Adult and Child	X			
	Knowledge		Adult and Child	X			
	Perceived benefits		Adult and Child	X			
	Social Support		Adult and Child	X			X
	Barriers		Adult and Child[d]	X		X	X
	Body weight norms		Adult and Child	X			X
	Health and well-being	Survey					
	Self-reported health status		Adult and Child[d]	X		X	X
	Life satisfaction		Adult	X		X	X
	Mental Health		Adult and Child	X		X	X
	Sleep		Adult and Child	X		X	X
	Health conditions		Adult and Child[d]	X		X	X
	Healthcare Access and Use		Adult			X	
	Substance use		Adult		X		
	COVID-19		Adult and Child			X	X
	Social Networks	Survey	Adult and Child	X			X
	Home Food Environment	Survey	Adult and Child[d]	X	X	X	X
	Food Shopping Behaviors	Survey	Adult	X		X	X
	Community Environment and Perceptions	Survey	Adult and Child	X	X	X	X
Moderators	Background Characteristics						
	Socio-Demographics	Survey	Adult and Child	X	X	X	X
	Employment/school	Survey	Adult and Child	X	X	X	X

ASA24®: Automated Self-Administered 24-h Dietary Assessment Tool.
[a] In progress.
[b] Planned.
[c] Only weight measurements were conducted in wave 3 due to Covid-19 restrictions.
[d] Measures were included in some of the indicated waves for children and all of the indicated waves for adults.

cluding loss of devices, reluctance to wear accelerometers due to concerns that their location was being tracked and/or undocumented status of some residents, and respondent burden. Three questions were included in the adult and child surveys. The first was a global measure of physical activity that asked respondents to rate their level of daily physical activity on a 10-point ordinal scale ("*On a scale of 1 to 10, where 1 means you spend most of your day sitting or lying down and 10 means you spend most of your day moving around on your feet, how physically active are you?*"). The second asked for the number of days in the past week [21] that respondents were physically active for at least 20 min at a stretch. The third question asked respondents how often they went for a walk, job, or run in their neighborhood in the past month, with response options including: did not go in the past month; 1–2 times in the past month, 3–4 times in past month, 1–2 times per week, and 3 or more times per week. These measures will allow us to directly assess if the redevelopment-related community improvements induced respondents to be more physically activity in their community.

Other Measures: In addition to the primary and intermediate outcomes, the study is also collecting rich data on a wide range of potential mediators, moderators, and risk factors for unhealthy weight that are summarized in Table 2. These measures include diet- and physical activity-related psychosocial risk factors, health and well-being, social networks, home food environment, food shopping behaviors, community environment and perceptions, and individual-level background and other characteristics. These measures will help unpack the "black box" and allow us to understand why the redevelopment did, or did not, affect BMI and obesity outcomes in expected ways, and whether it affected some residents more than others.

2.9. Other data collection

The study is also collecting additional ancillary data to provide a richer description of the changes that are expected to occur in the Watts community at large as a result of the redevelopment. The first is a series of in-depth interviews with community stakeholders in Watts, including non-profit neighborhood leaders in housing, public health, education, community safety, and business development; the Housing Authority of the City of Los Angeles (HACLA) staff or other government staff; law enforcement; housing redevelopment; and public housing resident leaders. The purpose of these interviews is to understand perceptions about the Jordan Downs redevelopment and other redevelopment efforts in Watts, how information and resources are shared and utilized throughout the neighborhood, and how these redevelopments ill impact resident and community well-being.

Second, the study is conducting annual audits of businesses and storefronts in Watts with the goal of examining how the business composition will change over time. For example, we will be able to assess what types of retail food outlets (e.g. convenience stores, supermarkets, small markets) are currently serving the community and how they change over time.

Third, the study is collecting food price data at multiple time points from grocery stores serving the community. Similar to previous studies [22,23], we collected prices for a market basket comparison of 103 items based on the USDA Thrifty Food Plan (TFP) and the Consumer Price Index market baskets of food, which included a selection of healthy and less healthy foods. We also customized the market basket to include items that were common among the diets of participants based on their 24-h food diary reports.

And lastly, we will compile time series data on local crime rates [24] and housing market indicators (prices, sales, foreclosures) to assess safety and gentrification.

2.10. Analysis plan

To examine the overall impact of the redevelopment on residents' BMI, overweight, and obesity, we will conduct a Difference-in-Difference (DID) analysis that will compare the changes in outcomes from baseline to annual follow-up periods between participants in the treatment group versus those in the control group, using linear regression for the BMI outcome and logistic regression for the overweight or obesity status.

Next, we will use a quasi-experimental stepped wedge design with a control group to disentangle the effects of the redevelopment components (housing, built- and social-environment). Specifically, the BE and SE effects are estimated between the full treatment and control samples similar to a DID analysis since all treated individuals are offered these components at the same time. The two effects are distinguishable given that the change in BE will occur before the new houses are ready and new mix-income residents can move in, incurring change in social-environment. Simultaneously, the model estimates the housing effect following a stepped wedge design [25,26], a relatively new type of clustered randomized control design, in which treatment individuals are sorted into clusters with exogenous variation and one cluster changes from pre- to post-treatment status every year. This design could be more powerful than a typical two-arm design because the treatment effect can be evaluated through both between- and within-cluster comparisons. It also effectively disentangles the time trend from the treatment effect as the time to receive the treatment varies exogenously across clusters. The three treatment components in the study are evaluated in a single model, which gives the capability to disentangle their relative contributions to the overall differences between treated and untreated individuals. The above analyses will also be conducted with the intermediate outcomes (e.g., diet, PA) since the change in BMI and obesity status could take a long time to be observed.

Next, we will assess potential reasons why the redevelopment did or did not impact residents' BMI, overweight or obesity. For example, we will examine how specific measures of BE, SE, and housing changed overtime, which helps to contextualize to what extent the redevelopment occurs as intended. We will also conduct a mediation analysis exploring the extent to which mediators (e.g., neighborhood cohesion, perceived safety, perceived barriers to healthy diets or physical activity) can explain the observed, or lack of observed, treatment effects. Finally, we will explore whether and how much the effects of the redevelopment may vary across subgroups defined by race-ethnicity, sex, and age (quartiles).

All analyses will adjust for individual-level socioeconomic and demographic characteristics and site-level covariates (e.g., site's racial-ethnic composition, # of housing units, poverty rate). We will also conduct missing data analysis, examining whether missing is at random or completely at random, and use multiple-imputation to handle missing data, when appropriate.

3. Power analysis and effect size projection

We show power analyses using the primary outcome, BMI, for the overall impact, as well as the BE and SE effects, under the assumption that the SE effect occurs one year after when the BE effect starts. We recruited a total of 609 adults from the treatment site and 259 from the control sites; of these, BMI data was obtained for 595 treatment adults and 257 control adults, with an average baseline BMI of 32.2 (SD = 8.1). We further assumed a cumulative retention rate of 70% by the end of Year 4, a Lag 1 autocorrelation of 0.8 for individuals from the same cluster, and an intra-cluster correlation of 0.01. For households with multiple individuals, we used the observed distribution to account for the potential within-household dependency. Using a Monte Carlo method similar to Hooper et al. [27], in combination with a line search, we simulated and analyzed data given the proposed model with replications, and calculated the proportion of times in which the null hypothesis was rejected. Power was determined as the proportion of times when the true effect used to simulate the data was not zero. We gradually increased the true effect size until the power became ≥80%. The simulation results suggest that our recruited sample would allow us to detect a minimum effect size of 0.27, or an expected average reduction of 2.19 in BMI, for the overall and BE effects, and an effect size of 0.29, or an expected average reduction of 2.35 in BMI, for the SE effect.

In addition, we recruited a total of 466 children 2–17 years old from JD and 238 from the control sites; of these, z-BMI data was obtained for 444 JD children and 230 control children, with an average z-BMI of 0.95 (SD = 1.2) at baseline. Using the same method as for the adult analysis, we are powered to detect a minimum effect size of 0.30, or an expected average reduction of 0.36 in z-BMI, for the overall, BE, and SE effects.

4. Baseline results

At the end of baseline data collection (March 2020), the study had recruited 868 adults and 704 children ages 2–17 years old. Among the respondents who participated in wave 1, 84% of adults and 67% of children returned for wave 2 participation.

Using baseline data, we compared participants' sociodemographic characteristics and primary outcomes across treatment and control groups using two-sample t-tests for continuous and binary measures and Pearson's chi-2 test for categorical measures. These comparisons are done separately for adults and children. Because our baseline data includes two waves of data for a subsample of participants, we also examined pre-trends in our primary outcomes – BMI, overweight or obesity, and obesity – for this subsample. Specifically, we tested whether changes in these outcomes between waves 1 and 2 were significantly different across treatment and control participants using a standard difference-in-difference linear regression specification [28].

Sociodemographic characteristics for the adult and child participants are shown in Table 3. Overall, most adult participants are female (76.8%). Sixty-two percent of adult participants are Hispanic and 36.0% are non-Hispanic Black. The majority of respondents have a high school education or less (76.3%) and have an annual household income of less than $15,000 (66.3%). When comparing characteristics across treatment and control groups, adults in the treatment group were significantly less likely to be female (74.4% vs. 82.6%; p = 0.008), were more likely to be Hispanic (68.0% vs. 49.0%; p-value of chi2 test <0.001), and had lower education level (p-value of chi2 test = 0.025) than control adults.

Among children, about half the participants were female (52.9%), 71.0% were Hispanic, and 25.6% were Non-Hispanic Black. Compared to the control group, children in the treatment group were older on average (10.8 years vs. 9.8 years; p = 0.002) and more likely to be Hispanic (75.8% vs. 61.8%; p < 0.001).

Descriptive statistics for primary outcomes are shown in Table 4. Among adults, the prevalence of obesity and of overweight or obesity was 57.2% and 81.3%, respectively. Among children, the prevalence of obesity and of overweight or obesity was 33.1% and 52.4%, respectively. There were no statistically significant differences between the treatment and control groups among children or adults at baseline in the three primary outcomes.

Fig. 2 shows the pre-treatment trends between waves 1 and 2 for the primary outcomes, by treatment group and respondent type, for the subsample that participated in both baseline waves. Among adults, the prevalence of overweight or obesity decreased from 85.9% in wave 1–84.7% in wave 2 for the treatment group, but this difference was not statistically significant (p = 0.656). In comparison, the prevalence of overweight or obesity increased slightly from 84.0% to 85.4% for the control group but was also not statistically significant (p = 0.741). The difference-in-difference estimate, which captures whether the shift from waves 1 to 2 was significantly different between treatment and control group, was not statistically significant for BMI (DID estimate = 3.2; p = 0.977), overweight or obesity (DID estimate = –2.6; p = 0.602), or obesity (DID estimate = 2.6; p = 0.708).

Among children, the prevalence of overweight or obesity increased slightly from 52.4% in wave 1–53.2% in wave 2 for the treatment group, but this difference was not statistically significant (p = 0.853). In comparison, the prevalence of overweight or obesity decreased from 57.3% to 52.4% for the control group but was also not statistically significant (p = 0.533). The difference-in-difference estimate was not significant for BMI z-score (DID estimate = –0.8; p = 0.972), overweight or obesity (DID estimate = 5.7; p = 0.528), or obesity (DID estimate = 1.6; p = 0.849).

Overall, these results indicate that there were no statistically significant differences between the treatment and control groups in the time trend or shift in the primary outcomes prior to the redevelopment, for both adults and children. Since these two waves covered the baseline period, a flat trend sets a good foundation for future observation of potential changes attributable to the redevelopment.

5. Discussion

The Watts Neighborhood Health Study has successfully recruited a cohort of adults and children from public housing developments in Watts, Los Angeles and has collected rich baseline data that will allow us to rigorously study the impact of the Jordan Downs redevelopment on residents' BMI and contributing risk factors. Importantly, the rede-

Table 3
Baseline sociodemographic characteristics of participants at study entry in the Watts Neighborhood Health Study, by Respondent Type and Treatment Group.

	Total	Treatment	Control	P-value for difference
Adults	N = 868	N = 609	N = 259	
Female, %	76.8	74.4	82.6	0.008
Age in years, mean (SD)	41 (15.1)	41.3 (15.7)	40.2 (13.8)	0.312
Race/ethnicity, %				<0.001
Hispanic	62.3	68.0	49.0	
Non-Hispanic Black	36.0	30.5	48.6	
Non-Hispanic Other	1.7	1.5	2.3	
Highest Level of Education, %				0.025
Grade 8 and Under	19.5	22.0	13.5	
Grade 9-11	20.5	20.4	20.8	
Grade 12/GED	36.3	35.5	38.2	
Beyond High School	23.6	22.0	27.4	
Household Income in 2017%				0.056
Less than $5k	30.6	30.5	30.8	
$5k to <$10k	17.3	15.5	21.9	
$10k - <$15k	18.4	19.3	16.0	
$15k - <$20k	14.1	13.3	16.0	
$20k +	19.6	21.3	15.2	
Average Household Size, mean (SD)	3.5 (2.0)	3.5 (2.0)	3.3 (2.1)	0.208
Married/Living as Married, %	26.5	28.1	22.8	0.103
Children (2–17 years)	N = 704	N = 466	N = 238	
Female, %	52.9	55.1	48.7	0.112
Age in years, mean (SD)	10.4 (4.1)	10.8 (4.1)	9.8 (4.1)	0.002
Race/ethnicity, %				<0.001
Hispanic	71	75.8	61.8	
Non-Hispanic Black	25.6	20.3	35.7	
Non-Hispanic Other	3.4	3.9	2.5	

Notes: p-value based on two-sample t-tests for binary and continuous measures and Pearson's chi-2 test for categorical measures.

Table 4
Primary outcomes at baseline in the Watts neighborhood health study, by respondent type and treatment group.

	Total	Treatment	Control	P-value for difference
Adults	N = 852	N = 595	N = 257	
Obese, %	57.2	55.1	61.9	0.068
Overweight or Obese, %	81.3	80.5	83.3	0.342
BMI, mean (SD)	32.2 (8.1)	32.0 (8.1)	32.8 (8.0)	0.186
Children (2–17 years)	N = 674	N = 444	N = 230	
Obese, %	33.1	33.1	33.0	0.987
Overweight or Obese, %	52.4	52.3	52.6	0.930
BMI z-score, mean (SD)	0.95 (1.2)	0.91 (1.2)	1.01 (1.1)	0.278

Notes: P-value are based on two-sample t-tests for binary and continuous measures and Pearson's chi-2 test for categorical measures.

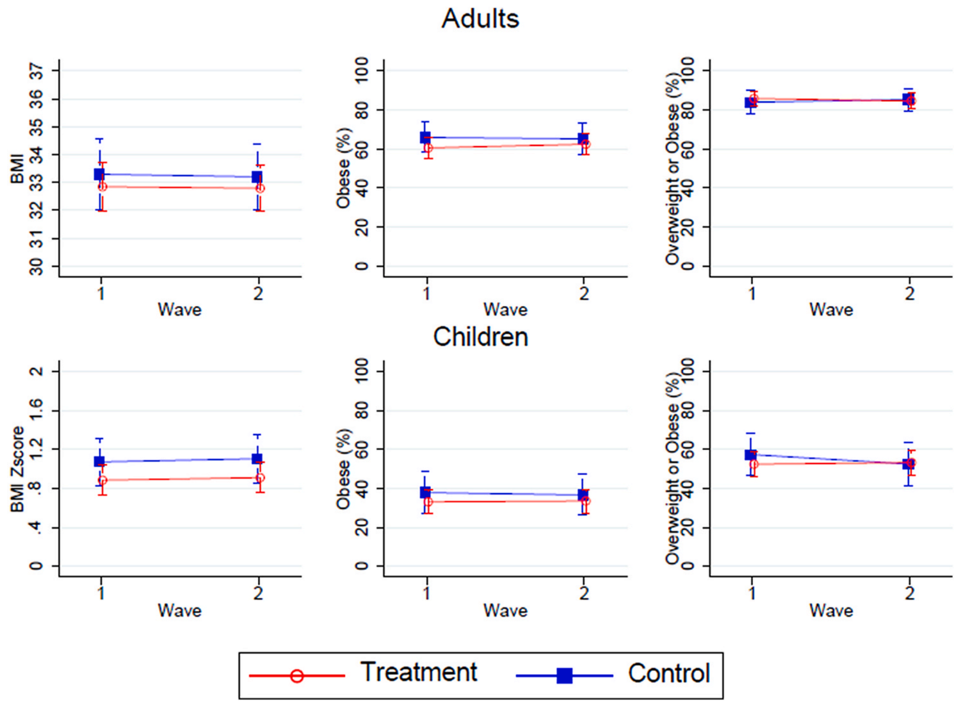

Fig. 2. Pre-treatment trends in primary outcomes, by respondent type and treatment group.

velopment is taking place in a community that is particularly high risk. The study sample has similar sociodemographic characteristics to typical public housing residents, who tend to be low-income, female, and racial-ethnic minorities [29]. The rates of overweight or obesity are alarmingly high in our study sample, over 85% among adults and over 50% in children. These estimates are similar compared to other studies in public housing residents [30,31] and are considerably higher than national estimates based on the National Health and Nutrition Examination Survey (NHANES) data [32].

There are several key strengths of this study. First, the natural experiment with a quasi-experimental stepped-wedge design provides a rigorous approach to assessing not just the overall impact of the redevelopment but also the contribution of the three broad components of the redevelopment – housing, social environment, and built environment. The similar pre-treatment levels and trends observed in the treatment and control groups for our primary outcomes provide strong support for the natural experiment study design.

Second, in contrast to the bulk of the existing literature that studies environmental changes that either change the food environment or the physical activity environment without altering both simultaneously [33], the JD redevelopment provides an opportunity to study the impact of a “whole of community” intervention that integrates approaches involving changes to *both* food and physical activity environments. There is growing consensus that such interventions are likely to be more successful and need to be evaluated more [33–35].

Third, our study also contributes to the limited evidence on housing quality and obesity. In contrast to the large literature on built environment and obesity, we are not aware of studies examining whether housing improvements reduce BMI and overweight/obesity in low-income populations. It is well known that disadvantaged populations are more likely to live in poor housing conditions. It is also well known that poor housing conditions are associated with a wide range of health conditions and risk factors [36–39], including infectious diseases, chronic illnesses, injuries, poor nutrition, psychological distress, poor sleep quality [40] and stress [36]. Chronic stress [41,42] and poor sleep quality [43] have in turn been shown to be important risk factors for obesity, making this an important line of research.

Fourth, our study will inform efforts being planned or underway to redevelop the depleted stock of public housing in the U.S. There are over 2 million residents living in public housing across the nation, with an average annual household income of $14,511, well below the Federal Poverty Line ($16,020 for a family of two in 2016 [44]. These residents tend to live in distressed housing, have extremely limited opportunities for physical activity and healthy food choices, and are racially and economically segregated [45–48]. Obesity rates in this population are substantially higher than in the general population and range between 45% and 49% [30,49]. The bulk of public housing in the U.S. was built in the post WWII era and has depleted considerably, leading many large cities to undertake, or plan for, redeveloping these communities. Our study can inform such efforts by elucidating whether and how the Jordan Downs redevelopment impacted residents' health and well-being.

Our study also has limitations. We focus on BMI as our primary measure, even though it is an imperfect measure of adiposity, mainly because of the practical advantage of conducting BMI assessments in community settings. In addition, our measures of dietary intake and physical activity are largely based on self-reports, which can be subject to measurement error. We try to mitigate these concerns by collecting this information using different assessments methods, and, in some instances, collecting objective measures (e.g. accelerometry) for a subsample to allow within sample adjustments for measurement error (via regression calibration). But ultimately, these choices were made while balancing the need to minimize respondent burden and distrust with that of obtaining the rich data necessary for unpacking the mechanisms underlying the redevelopments' impact on residents. Other limitations include potential lack of generalizability of our findings. Our study only includes households from three public housing sites in Los Angeles and may not generalize to other settings. Moreover, while our study recruited 62% of the units in Jordan Downs and the sociodemographic characteristics of the JD sample were similar to the overall JD population [13], there could be unobserved differences between those who did and did not participate in the study. .

Finally, a challenge that our study faced, but that was not unique to us, was the COVID-19 pandemic, which hit LA County in March 2020, just before wave 3 data collection was to commence. We were able to go into the field on time and conduct surveys via phone and video/audio conferencing applications. However, we were unable to obtain in-person anthropometry assessments in wave 3 due to the COVID-19 restrictions, and instead collected self-reports of height and weight. We plan to use statistical techniques such as regression calibration techniques [50,51] to "correct" for bias in self-report data using height and weight measurements and self-reports from respondents in other waves of the study. In terms of other impacts on our study, the pandemic has led to a slight delay in the redevelopment timeline since relocations were paused for several months in 2020. However, construction was deemed essential business in LA County so construction continued, although the timeline was also delayed, likely due to supply chain bottlenecks and spread of the virus. However, it is important to note that both treatment and control sites faced the same COVID-19 restrictions, so the overall study design is still largely the same (with some changes in the size and timing of the treatment clusters), although we expect there to be delayed realization of some of the anticipated effects (e.g. indoor physical activity, social environment effects).

In summary, the Watts Neighborhood Health Study leverages a unique opportunity to generate significant knowledge about whether and how major improvements to housing and the built- and social-environments can affect residents' BMI outcomes and related behaviors in high-risk communities.

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.

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