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Does the built environment influence the effectiveness of behavioral weight management interventions?

Shannon N. Zenk[a,*], Elizabeth Tarlov[a,b], Coady Wing[c], Sandy Slater[d,e,1], Kelly K. Jones[a,2], Marian Fitzgibbon[d,f], Lisa M. Powell[d,e]

[a] University of Illinois at Chicago College of Nursing, 845 S. Damen Ave., Chicago, IL 60612, USA
[b] Edward Hines Jr. Veterans Affairs Hospital, Hines, IL 60141, USA
[c] Indiana University School of Public and Environmental Affairs, Bloomington, IN 47405, USA
[d] University of Illinois at Chicago Institute for Health Research and Policy, Chicago, IL 60612, USA
[e] University of Illinois at Chicago School of Public Health, Chicago, IL 60612, USA
[f] University of Illinois at Chicago Department of Pediatrics, Chicago, IL 60612, USA

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ABSTRACT

Outcomes of behavioral lifestyle interventions for promoting weight loss vary widely across participants. The effectiveness of a weight management intervention may depend on a person's environmental context. This study compared short- and longer-term effects of a structured nationwide weight management program for people living in neighborhoods with different levels of walkability and different access to recreational places (parks, fitness facilities). Drawing on the health production model, we tested competing hypotheses for whether treatment effects of the program complement environmental supports or substitute for environmental constraints. We studied the US Department of Veterans Affairs (VA) MOVE! weight management program using VA electronic heath record data (2009–2014) and a difference-in-differences design with an inverse propensity score matched comparison group. A total of 114,256 program participants and 498,494 non-participants comprised the sample. Built environment features were measured within one-mile of each person's home. We estimated program effects on body mass index (BMI) for subgroups with different built environments at 6-, 12-, 18-, and 24-month follow-up using linear regressions with person and year fixed effects. At 6 months, the program reduced BMI by 0.4–0.6 kg/m^2 among men and 0.3–0.5 kg/m^2 among women. The effect diminished at 12, 18, and 24 months. The program effect did not vary significantly across subgroups with different walkability, park access, or fitness facility access. The MOVE! program was not sensitive to environmental context. Results did not lend support to either hypothesis that the MOVE! program complements or substitutes for a person's built environment to affect weight management outcomes.

1. Introduction

Weight loss is a coveted goal for many around the globe, with obesity prevalence tripling between 1975 and 2014 (NCD Risk Factor Collaboration (NCD-RisC), 2016). Obesity is a particular problem in the United States (U.S.), with 37.9% of men and 41.1% of women obese (Hales et al., 2017). Even modest weight loss is associated with health improvements (Ryan and Yockey, 2017). Many of the estimated 93 million U.S. obese adults are trying to lose weight, yet effective behavioral lifestyle interventions for promoting weight loss and weight loss maintenance fail to achieve long-term results (Hales et al., 2017; MacLean et al., 2018; MacLean et al., 2015; Bray et al., 2016). Overall, many individuals are successful at short-term weight loss, but are unable to maintain those losses (Brownell, 2010). And responses to interventions vary widely across individuals (MacLean et al., 2018; MacLean et al., 2015; Bray et al., 2016). A better understanding of why evidence-based behavioral interventions have under-performed in real-world settings is needed to improve outcomes, reduce obesity, and

* Corresponding author at: Department of Health Systems Science, University of Illinois at Chicago College of Nursing, 845 S Damen Ave., 9th Floor, Chicago, IL 60612, USA.

E-mail addresses: szenk@uic.edu (S.N. Zenk), elizabeth.tarlov@va.gov (E. Tarlov), cwing@indiana.edu (C. Wing), sslater@uic.edu, sandra.slater@cuw.edu (S. Slater), kellykj@uic.edu, kjones1@sesync.org (K.K. Jones), mlf@uic.edu (M. Fitzgibbon), powelll@uic.edu (L.M. Powell).

[1] Present Address: Concordia University Wisconsin School of Pharmacy, Mequon, WI 53097 USA.
[2] Present Address: National Socio-Environmental Synthesis Center, Annapolis, MD 21401 USA.

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improve health. One hypothesis is that resources and constraints in people's environments affect their ability to lose weight (Sallis et al., 1998; Saelens et al., 2018; Zenk et al., in press).

Research shows that features of the built environment are associated with physical activity and body weight outcomes. For example, people living within walking distance of destinations and near direct routes between home and these destinations tend to be more physically active and to have lower body mass index (BMI) (Mackenbach et al., 2014; Barnett et al., 2017; Adkins et al., 2017; Creatore et al., 2016; Cerin et al., 2018). Living near parks and fitness facilities may also facilitate physical activity and lower BMI (Barnett et al., 2017; Smith et al., 2017; Ranchod et al., 2013; Christian et al., 2017). It is possible that these environmental features also affect weight management. Given that neighborhoods vary widely in these resources (Wen et al., 2013; Powell et al., 2006; Bereitschaft, 2017), differences in access to built environment resources may help explain why some people in behavioral weight management interventions lose weight and others do not.

Drawing on nationwide data (Zenk et al., 2018a), to our knowledge, this is the first study to compare the short- and longer-term weight loss effects of a behavioral weight management program intervention between people living in neighborhoods with different levels of walkability and different access to recreational places (parks, fitness facilities). Applying Grossman's model of health production, we propose that the concept of complements and substitutes provides a useful framework for understanding treatment effect heterogeneity in behavioral weight management interventions (Grossman, 1972). Briefly, in this model, people partly produce their health by combining various inputs such as time with other goods and services. Some inputs may be complements in a health production function if they produce the most health when combined. Other inputs may be substitutes in that they produce similar quantities of health. As applied here, if the intervention complements environmental supports, treatment effects will be larger for people living in environments that are more walkable and where recreational places are more accessible. If the intervention substitutes for environmental constraints, treatment effects will be larger for people living in environments that are less walkable and with fewer recreational places.

2. Methods

2.1. Design, intervention, and data

This study used a generalized difference-in-differences design with an inverse propensity score matched comparison group. We studied the US Department of Veterans Affairs (VA) MOVE! program, a nationwide, evidence-based weight management program modeled after the Diabetes Prevention Program for US military veterans receiving VA healthcare (Kinsinger et al., 2009; Maciejewski et al., 2018). As a behavioral weight management program, MOVE! emphasizes education and support for use of tools such as self-management techniques to adopt and sustain behavior change. This includes development of new physical activity habits (e.g., walking for transportation) and problem-solving skills to identify and address challenges such as those presented by resources, bad weather, time limitations, and others such as using local fitness facilities. Participants receive an individualized treatment plan as well as education and counseling to support behavior change efforts. We used 2009–2014 data from the VA Corporate Data Warehouse, a repository of data on VA patients that comes from the electronic health record and other sources, as well as Medicare claims data. We exploited home address geocodes to link the patient data to secondary data on the environment. Prior publications (Tarlov et al., 2018; Zenk et al., 2018a, 2018b) and Supplemental File 1 provide additional information on the MOVE! program and study methodology, not covered below.

2.2. Sample

Our sample was derived from a cohort of men (n = 2,471,824) and women (n = 199,839) aged 20–80 years at baseline who received primary healthcare services in the VA between 2009 and 2014 and lived in metropolitan counties of the continental U.S. (Zenk et al., 2018a). The MOVE! group was cohort members who had at least two MOVE! visits within a 6-month period (or intervention period) and who also had no MOVE! visits within the 12 months prior to the first MOVE! visit (start date). In addition, each MOVE! participant needed at least one weight measurement taken around the time of his/her first MOVE! visit and at least one weight measurement taken at either 18-months or 24-months follow up. We constructed a comparison group from the set of cohort members who did not participate in MOVE!. We assigned each member of the comparison group a MOVE! pseudo-start date with probability proportional to the relative frequency of start dates in the MOVE! group and used the same weight measurement inclusion criteria as for the MOVE! group.

We estimated propensity scores for each sample member by fitting logistic regressions of the MOVE! participation indicator on a set of over 120 baseline covariates (Zenk et al., 2018a). We formed inverse propensity score weights and used them to reweight the comparison group so that it resembled the MOVE! group at baseline. After applying the weights, the standardized mean differences in covariates between the MOVE! group and the matched comparisons were < 0.05 standard deviations for all of the covariates, which indicates an excellent match between the MOVE! and comparison groups (Ho et al., 2007).

2.3. Measures

2.3.1. Body mass index

The electronic health record contains height and weight measurements recorded during VA healthcare encounters. We constructed person-level measures of BMI (weight in kg/height in m^2) at the start of the intervention period and at up to four follow-up points taken approximately 6-, 12-, 18-, and 24-months after the start date.

2.3.2. Environmental exposures

We obtained each person's home address geocodes at the end of each VA fiscal year (September 30). We constructed environmental measures on up to an annual basis using the centroids of a 30 m × 30 m grid (approximately 9 billion grid cells) covering the continental U.S. Each person's home address was assigned to a cell on the grid and the person's environmental variables were assigned the values of the features of the cell (Zenk et al., 2018a).

We developed annual measures of walkability within one mile of the person's home address to reflect three important components (density, destination access, and design) using a 5-item index that comprises population density (United States Census Bureau, n.d.-a), housing unit density (United States Census Bureau, n.d.-a), destination (i.e., retail, accommodation/food service, arts/entertainment/recreation) density as measured using employment data (United States Census Bureau, n.d.-b), street intersection density (NAVTEQ), and percentage of street intersections that were at least 4-way (NAVTEQ). All these indicators were based on annually updated data except street intersections for which we had three years of data: 2010, 2011, and 2013. We standardized each item to have a mean of 0 and a standard deviation of 1 for the cohort across the six years. The walkability index was the person's average score on the five standardized items (Cronbach's alpha = 0.83). Walkability scores were categorized into quartiles of the cohort's distribution across the six years, with low as the reference category.

We constructed measures of geographic access to recreational places within one mile. Park access was measured as park acreage at two time points (2010, 2014). To enhance completeness, we merged and deduplicated two sources of park data (NAVTEQ, TeleAtlas). Fitness facility access was measured using annual data as a count of facilities, operationalized using 62 separate primary standard industrial classification (SIC) codes (InfoUSA). Both park access and fitness facility access were categorized as no park/facility (reference category) and tertiles of the non-zero distribution of park acreage and facility counts for the cohort.

2.3.3. MOVE! participation

We assessed MOVE! exposure using clinic stop codes, which define the specific clinical service the person received. We used a dichotomous variable in the analysis (1 = MOVE! participant, 0 = comparison).

2.3.4. Covariates

Regression models controlled for time-varying individual-level measures of marital status and ten chronic health conditions often associated with BMI, diet, and/or physical activity: breast cancer, cerebrovascular disease, colon cancer, congestive heart failure, depression, diabetes, hyperlipidemia, hypertension, myocardial infarction, and osteoarthritis. Time-varying area-level covariates included census division, county-level urbanicity (Ingram and Franco, 2014), census tract poverty rate and median household income (United States Census Bureau, n.d.-a), season using the month and year of weight measurements, and accessibility of supermarkets, grocery stores, and convenience stores (InfoUSA), as well as fast food restaurants (Dun & Bradstreet) within one mile. We also controlled for number of days between the target follow-up dates and the actual weight measurement date, VA facility where the person was most frequently seen, and distance to the nearest VA facilities for outpatient and inpatient care. Four dummy variables indicated whether the observation was 6-, 12-, 18-, or 24-month follow up.

2.4. Statistical analyses

The goal of our study is to estimate the causal effects of the MOVE! program over time and across sub-groups of people who are exposed to different built environments. To estimate MOVE! effects on BMI at each follow up, we fit the following model using inverse propensity score weighted linear regressions:

$$BMI_{it} = X_{it}\alpha + \sum_{m\in\{6,12,18,24\}} [\beta_m (Move_i \times Post(m)_{it}) + \delta_m (Move_i \times Post(m)_{it} \times Built_{it})] + \epsilon_{it}$$

$Move_i$ is a binary variable set to one if the person is a MOVE! participant, $Post(m)_{it}$ is a dummy variable set to one for all follow-ups recorded m or more months after the person's baseline for values of $m = \{6,12,18,24\}$, and $Built_{it}$ is a vector of built environment variables. X_{it} is a vector that includes covariates and main effects. β_6 is the difference-in-differences estimate of the program effect in the built environment reference group at the 6-month follow up. The effect is $\beta_6 + \beta_{12}$ at 12 months; $\beta_6 + \beta_{12} + \beta_{18}$ at 18 months, and $\beta_6 + \beta_{12} + \beta_{18} + \beta_{24}$ at 24 months. Adding in the relevant δ_m estimates makes it possible to compute period-specific program effects in subgroups with different built environments. We also include person and year fixed effects.

Our analysis adjusts for a broad range of possible confounders that might lead to biased estimates of the treatment effect in simpler research designs. The inverse propensity score weights help ensure that MOVE! participants and comparisons have very similar measured characteristics at baseline. The generalized difference-in-differences regressions account for unmeasured, time-invariant confounders that may have survived the matching procedure. In addition, the models account for unmeasured time-varying factors that may have affected BMI as long as the time-varying factors affect both the participants and matched comparisons in the same way.

In our main model specifications, within-person changes in built environment come from two sources of variation: residential moves (i.e., people moving from one address to another) and neighborhood change, or the development or closure/destruction of fitness facilities, retailers, streets, etc., for people who stay at the same address. One concern is that residential moves may be prompted by changes in health status or health preferences and that these factors may confound the effects of the change in environmental features. To guard against this possible source of bias, we also estimated the models in a subset of “stayers” who remained living within 0.25 mile of their home address at baseline throughout the study period. Among stayers, the models identify subgroup program effects using only variation from neighborhood change. This variation is less plausibly connected to a person's motivation to lose weight.

All models were estimated using the inverse propensity score weights, and standard error estimates allowed for clustering of patients within counties at baseline using a Huber-White cluster robust variance matrix. Analyses were conducted separately for men and women because prior research has shown gender differences in weight loss and built environment influences (Jun and Namgung, 2018; Hollis et al., 2008), and in our study, they differ in their demographic profiles. We conducted analyses in 2018 using Stata version 14. This study was approved by the institutional review boards of the University of Illinois at Chicago and Edward Hines, Jr. VA Hospital.

3. Results

Table 1 shows propensity-score weighted descriptive statistics for the MOVE! group and the comparison group, separately for men (n = 98,871 MOVE! participants; n = 461,302 comparisons) and women (n = 15,385 MOVE! participants; n = 37,192 comparisons). Supplemental Table 1 shows corresponding descriptive statistics among stayers.

3.1. Short-term effects on BMI at 6 months

The Fig. 1 plots estimate for the effect of MOVE! on BMI at 6, 12, 18, and 24 months for subgroups with different levels of walkability and access to parks and fitness facilities, separately for men and women controlling for covariates. Table 2 shows the MOVE! effect on BMI change at 6 months and incremental effects on BMI at 12, 18, and 24 months. At 6 months among men, MOVE! participation reduced BMI by about 0.4–0.6 kg/m^2, regardless of the built environment (all p-values < 0.01, estimates with 95% CI shown in Supplemental Table 2). However, as shown in the left panel of Table 2, there were no statistically significant differences in MOVE!-related weight loss at 6 months between subgroups with more compared to less built environment supports near their home. For example, those with higher walkability did not lose more weight, on average, than those with low walkability. At 6 months among women, MOVE! participation reduced BMI by 0.3–0.5 kg/m^2, regardless of the built environment (all but one p-value < 0.05, estimates with 95% CI shown in Supplemental Table 2). However, the 6-month MOVE! effect did not differ significantly between subgroups with more compared to less built environment supports (left panel of Table 2).

3.2. Longer-term effects on BMI at 12, 18, and 24 months

Among men, MOVE! participation reduced average BMI from baseline by 0.3–0.4 kg/m^2 by 12 months, 0.2–0.4 kg/m^2 by 18 months, and 0.1–0.3 kg/m^2 by 24 months, regardless of the environment (Fig. 1; estimates, 95% CI, and p-values in Supplemental Table 2). In other words, the treatment effect of the MOVE! program decreased in the two years after the first visit which suggests that participants gained back at least some of their initial weight loss. However, as the three right most panels of Table 2 show, the erosion in the initial treatment effect did not differ across subgroups with different built environment supports.

Table 1
Propensity score-weighted descriptive statistics of sample characteristics at baseline for MOVE! participants and comparisons, U.S. military veterans using VA healthcare (2009–2014).

	Men		Women	
	MOVE! participants	Comparisons	MOVE! participants	Comparisons
Total N	98,871	461,302	15,385	37,192
Body mass index (BMI), mean (SD)	36.2 (6.6)	36.2 (3.1)	35.4 (6.5)	35.5 (4.1)
Age, mean (SD)	60.0 (9.8)	60.2 (4.6)	50.1 (10.8)	50.2 (7.0)
Race, %				
Non-Hispanic White	63.1	62.8	49.2	49.2
Non-Hispanic Black	24.1	24.4	38.4	38.6
Non-Hispanic Other	2.1	2.1	2.9	3.0
Hispanic	5.6	5.7	4.6	4.5
Unknown	5.0	5.0	4.9	4.7
Marital status, %				
Married	55.0	54.9	30.8	30.6
Separated/divorced	25.2	25.2	37.3	37.6
Widowed	3.2	3.2	3.9	3.7
Single	16.1	16.2	27.3	27.5
Unknown	0.5	0.5	0.7	0.6
Health status, %				
Breast cancer	< 0.1	0.1	2.5	2.5
Colon cancer	0.8	0.8	0.3	0.3
Cerebrovascular disease	6.0	6.1	3.2	3.3
Congestive heart failure	8.0	8.2	2.1	2.1
Depression	36.2	36.6	53.2	53.5
Diabetes	45.2	46.0	21.5	21.5
Hyperlipidemia	63.9	64.8	41.3	41.5
Hypertension	73.8	74.7	46.0	46.2
Myocardial infarction	3.8	3.9	0.8	0.9
Osteoarthritis	22.6	23.6	20.1	21.3
Census tract characteristics, mean (SD)				
% below poverty	15.4 (12.0)	15.5 (12.0)	16.1 (11.7)	16.2 (11.7)
Median household income	52,911 (21,868)	52,847 (21,854)	51,309 (20,339)	51,194 (20,238)
Urbanicity, %				
Large central metro	32.0	32.1	32.1	32.2
Large fringe metro	22.8	22.6	21.5	21.5
Medium metro	30.0	29.9	32.6	32.4
Small metro	15.1	15.5	13.9	14.0
Census division, %				
New England	4.6	4.7	2.6	2.7
Middle Atlantic	10.8	10.8	8.0	8.1
East North Central	17.8	18.2	14.2	15.0
West North Central	6.5	6.4	6.3	5.5
South Atlantic Delaware	21.1	21.0	26.4	26.6
East South Central	4.9	4.6	6.4	6.2
West South Central	12.3	11.7	15.4	15.0
Mountain Arizona	10.6	11.1	10.2	10.7
Pacific Alaska	11.4	11.6	10.5	10.4
Walkability within 1 mile, %				
Low (−1.09 to −0.59)	21.2	21.2	18.2	18.5
Low-moderate (−0.59 to −0.16)	24.0	23.4	26.5	26.3
Moderate-high (−0.16 to 0.35)	25.3	25.3	28.5	27.6
High (0.35+)	29.6	30.2	26.9	27.6
Park area within 1 mile, %				
No park	29.3	28.9	30.9	30.2
Low (0.22–27.57 acres)	22.6	22.9	23.7	23.8
Moderate (27.80–78.07 acres)	23.4	23.9	22.6	23.0
High (78.06+ acres)	24.7	24.4	22.8	23.0
Fitness facilities within 1 mile, %				
No facility	25.9	25.6	25.5	25.3
Low (1, 2)	29.0	28.1	29.9	30.0
Moderate (3, 4)	18.2	18.3	18.4	18.3
High (5+)	27.9	28.0	26.1	26.4

Among women, the initial 6-month effect of MOVE! participation decreased substantially from baseline at 12, 18, or 24 months for each subgroup (Fig. 1; estimates, 95% CI, and p-values in Supplemental Table 2). The basic tapering-off pattern did not vary substantially across women living in different built environments. One exception is that the effect of the MOVE! program appeared to become stronger at 12 months for women with high access to fitness facilities ($b = -0.510$, $p < 0.01$; Table 2). However, the larger treatment effects in this high fitness facility subgroup disappeared almost completely by 24 months (Table 2 and Fig. 1).

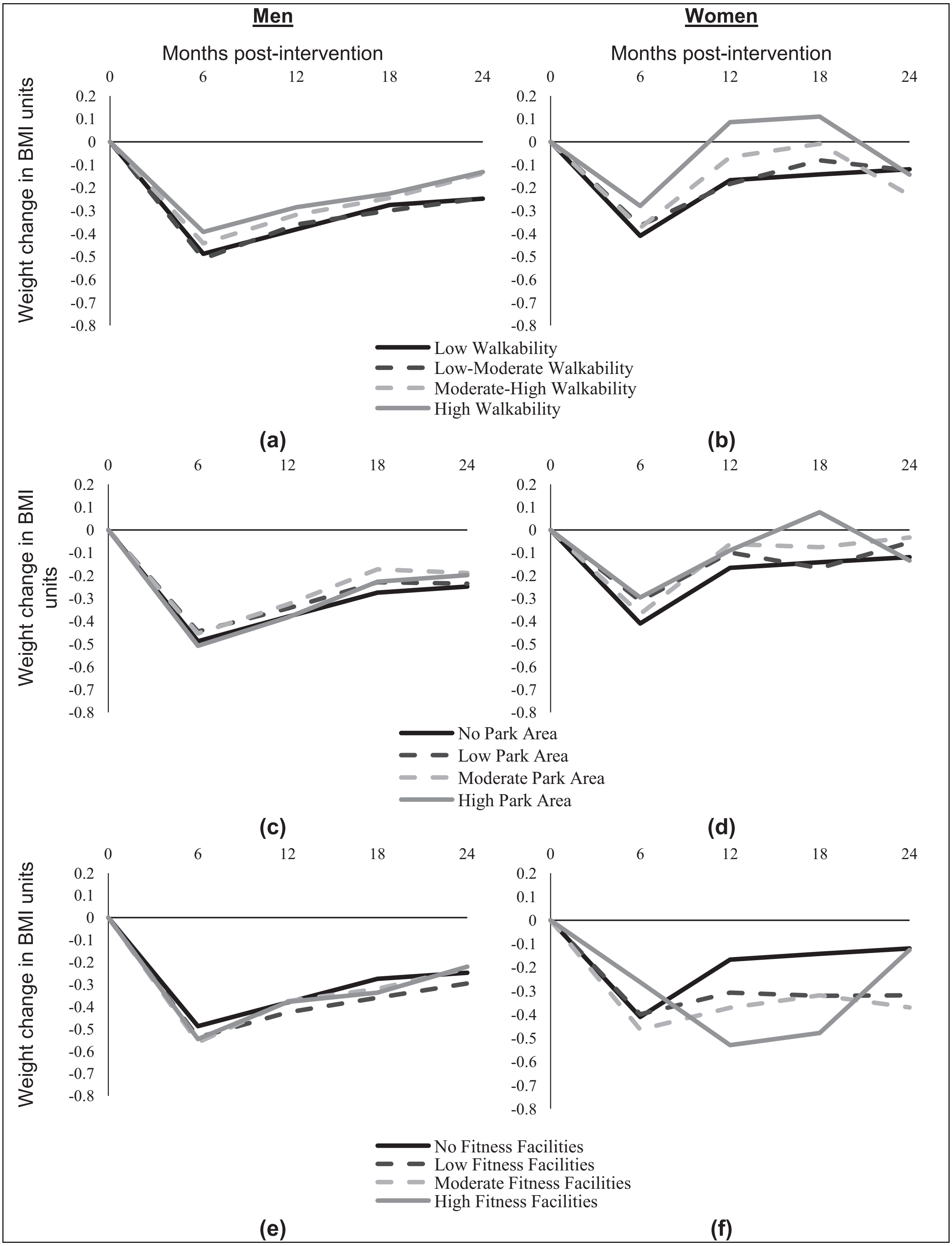

Fig. 1. MOVE! weight management program effect on BMI change from baseline at 6, 12, 18, and 24 months for subgroups with different walkability for (a) men and (b) women; park area for (c) men and (d) women; and fitness facility access for (e) men and (f) women.

3.3. Sensitivity results

Results were similar when the analyses were restricted to stayers (Supplemental Tables 3 and 4). Models with different operational definitions of our built environment measures, i.e., 0.25-mile walkability, 3-mile fitness facility count, 0.25-mile park area, and 0.25-mile and 1-mile park counts, did not differ from those presented here in meaningful ways (not shown).

Table 2
MOVE! effect on 6-month BMI change and incremental BMI change at 12, 18, and 24 months, U.S. military veterans using VA healthcare (2009–2014)[a].

	MEN (n = 560,173)											
Months	6 months [b]			12 months [c]			18 months [c]			24 months [c]		
	b	SE	p-Value	b	SE	p-Value	B	SE	p-Value	b	SE	p-Value
MOVE! x post [d]	−0.488	0.025	< 0.01	0.107	0.026	< 0.01	0.106	0.026	< 0.01	0.027	0.033	0.42
Walkability												
Low	Ref	–	–	Ref	–	–	Ref	–	–	Ref	–	–
Low-moderate	−0.021	0.036	0.55	0.042	0.039	0.28	−0.045	0.036	0.22	0.028	0.046	0.54
Moderate-high	0.046	0.052	0.38	0.018	0.045	0.69	−0.033	0.043	0.45	0.079	0.056	0.16
High	0.095	0.082	0.25	0.001	0.051	0.99	−0.046	0.052	0.38	0.067	0.061	0.27
Park area												
No park	Ref	–	–	Ref	–	–	Ref	–	–	Ref	–	–
Low	0.043	0.036	0.23	−0.006	0.034	0.86	0.009	0.031	0.78	−0.033	0.043	0.44
Moderate	0.034	0.032	0.29	0.020	0.036	0.58	0.047	0.030	0.12	−0.042	0.042	0.32
High	−0.021	0.040	0.60	0.017	0.034	0.16	0.051	0.034	0.13	0.002	0.044	0.97
Fitness facilities												
No facility	Ref	–	–	Ref	–	–	Ref	–	–	Ref	–	–
Low	−0.050	0.046	0.28	0.005	0.035	0.88	−0.041	0.034	0.22	0.038	0.049	0.43
Moderate	−0.073	0.062	0.24	0.078	0.042	0.06	−0.051	0.040	0.20	0.065	0.058	0.26
High	−0.057	0.069	0.41	0.060	0.043	0.17	−0.065	0.041	0.12	0.090	0.052	0.08

	WOMEN (n = 52,577)											
Months	6 months [b]			12 months [c]			18 months [c]			24 months [c]		
	b	SE	p-Value	b	SE	p-Value	b	SE	p-Value	b	SE	p-Value
MOVE! x post [d]	−0.410	0.095	< 0.01	0.243	0.104	0.02	0.025	0.084	0.76	0.021	0.094	0.82
Walkability												
Low	Ref	–	–	Ref	–	–	Ref	–	–	Ref	–	–
Low-moderate	0.045	0.093	0.63	−0.061	0.118	0.61	0.078	0.13	0.55	−0.066	0.158	0.68
Moderate-high	0.035	0.108	0.75	0.065	0.161	0.68	0.033	0.209	0.87	−0.246	0.198	0.21
High	0.131	0.131	0.32	0.122	0.193	0.53	−0.001	0.214	1.00	−0.275	0.226	0.22
Park area												
No park	Ref	–	–	Ref	–	–	Ref	–	–	Ref	–	–
Low	0.099	0.080	0.22	−0.031	0.120	0.80	−0.095	0.090	0.29	0.093	0.125	0.46
Moderate	0.041	0.095	0.67	0.064	0.140	0.65	−0.039	0.119	0.74	0.021	0.149	0.89
High	0.114	0.083	0.17	−0.036	0.110	0.74	−0.012	0.103	0.90	−0.079	0.117	0.50
Fitness facilities												
No facility	Ref	–	–	Ref	–	–	Ref	–	–	Ref	–	–
Low	0.011	0.078	0.89	−0.152	0.120	0.21	−0.038	0.115	0.74	−0.019	0.131	0.88
Moderate	−0.054	0.095	0.57	−0.150	0.148	0.31	0.028	0.131	0.83	−0.073	0.158	0.64
High	0.147	0.152	0.33	−0.510	0.152	< 0.01	0.027	0.133	0.84	0.330	0.166	0.05

[a] Difference-in-differences (DID) estimate (b) with standard error (SE) of the effect of MOVE! on BMI change from linear regression models with person and year fixed effects and the following covariates: marital status, 10 chronic health conditions, census tract median household income, census tract poverty rate, census division, urbanicity, VA facility, distance to the nearest VA facilities for outpatient and inpatient care, number of days from each target follow-up date and the actual weight measurement date, supermarkets, fast food restaurants, convenience stores, and grocery stores.
[b] At 6 months, these are estimates of MOVE! effect on BMI change from baseline.
[c] At 12, 18, and 24 months, these are estimates of MOVE! effect on incremental BMI change from the prior time point.
[d] DID estimate for the effect of MOVE! for reference (ref) subgroup with low walkability, no park, and no fitness facility.

4. Discussion

We found limited evidence that the effectiveness of the MOVE! weight management program differed for subgroups of participants residing in different types of physical activity-relevant built environments. Regardless of walkability and fitness facility and park access, the MOVE! program reduced participant BMI during the duration of the program (24 months). However, the program effect began to shrink by 12 months and beyond, consistent with prior research (MacLean et al., 2015). Our results do not lend support to either the complementarity or the substitution hypothesis. Indeed, the results revealed that MOVE! program did not have improved or diminished outcomes among participants who lived in environments that were either more walkable or where recreational places were more accessible. The few statistically significant associations involving the built environment were not beyond what one might expect by chance given the number of statistical tests (Rothman, 1990).

Our finding that the MOVE! program was effective in achieving short-term, albeit modest weight loss even for those living where features of the environment were not supportive of physical activity is important. The VA functions as a safety-net for low-income and otherwise disadvantaged veterans. In addition to providing lifetime healthcare coverage, this commitment is borne out in other ways including in MOVE! where, for example, program materials specifically address financial concerns in regard to physical activity resources such as use of public spaces (e.g., see https://www.move.va.gov/MOVE/handouts.asp#physical). Further, MOVE! was intentionally designed for flexibility in implementation by VA facilities, to respond to local needs and resources. It may be that VA's mission-driven culture and safety-net commitment together with this flexibility in MOVE! program implementation has resulted in a weight management program that is equally successful in addressing the needs of those living in less and more supportive environments.

Although modest, the weight loss induced by MOVE! participation we found was on par with that in other studies (Ackermann et al., 2015). Moreover, the pattern of initial weight loss and regain starting at

12 months we observed in the MOVE! program is typical of weight management efforts (MacLean et al., 2015; Brownell, 2010). As summarized by MacLean and colleagues (MacLean et al., 2015), participants tend to lose weight (an average of 8% of their body weight) in the first 6 months after initiating behavioral changes required for weight loss and then begin to regain weight each year, with even greater weight regain initially. Poor weight loss maintenance is thought to reflect biological adaptations that increase appetite and reduce energy expenditure, decline in behavioral adherence as a result of psychological and other factors, and environmental exposures that promote poor diet and insufficient physical activity (MacLean et al., 2018; MacLean et al., 2015). Identifying the biological, psychosocial, behavioral, and environmental factors that influence short- and longer-term weight management intervention outcomes and the tremendous heterogeneity found in individual outcomes is a priority in the field and is one of the motivations underlying this study. Exploiting the variation in MOVE! program elements across VA facilities, we are currently investigating how the "fit" between specific MOVE! program elements (e.g., staffing disciplinary mix and percent effort, provision of on-site physical activity space) and residential environment features affect program outcomes.

This study extends a small body of studies examining whether the effectiveness of adult physical activity and lifestyle interventions depends on the environment in which individuals live (Zenk et al., in press). Prior studies typically had fewer than 500 people across the intervention and control groups and tested effects at one follow-up point between 3 and 12 months after the start of the intervention. The studies also varied in design and use of objective or self-report measures of the environment and physical activity. All but one (Jilcott Pitts et al., 2017) tested for treatment effect heterogeneity in physical activity interventions. Two studies found evidence of substitution. Using a one-group, pre-post design, Jilcott-Pitts and colleagues found intervention participants who lived farther from fitness facilities had greater increases in physical activity at 6 months (Jilcott Pitts et al., 2017). But they found no evidence that these effects extended to 6-month weight change or that 6-month physical activity or weight changes differed by walkability. Using data from two randomized controlled trials of physical activity interventions, Kerr and colleagues found that male intervention participants living in low walkable neighborhoods spent more time walking at 12 months, while those in high walkable neighborhoods did not (Kerr et al., 2010). However, treatment effects did not differ by walkability among women. Other studies found no evidence that treatment effects on physical activity differed by walkability (King et al., 2017; Mama et al., 2015; Perez et al., 2018; Zenk et al., 2009; Michael and Carlson, 2009; King et al., 2006) or access to recreational places (Perez et al., 2018; Zenk et al., 2009; Merom et al., 2009).

It is possible that other environmental factors not studied here may be more influential, although other features examined to date have generally not contributed to treatment effect heterogeneity either. Two studies found no support for aesthetics as an environmental moderator of physical activity intervention effects (Kerr et al., 2010; Zenk et al., 2009), while three found intervention effects differed by neighborhood aesthetics (Perez et al., 2018; King et al., 2006; Merom et al., 2009). Some research showed that crime- and traffic-related safety altered lifestyle intervention effectiveness (King et al., 2006; Schoeny et al., 2017), although most research did not (Jilcott Pitts et al., 2017; Kerr et al., 2010; Perez et al., 2018; Zenk et al., 2009; Merom et al., 2009; Oh et al., 2010).

4.1. Strengths and limitations

This study's strengths include its relatively long 24-month follow up, large sample with ample statistical power to detect small treatment effects, well-matched comparison groups, and nationwide coverage with wide variation in the residential environments experienced by participants. These elements provided a rare opportunity to study whether the residential environment is a source of treatment effect heterogeneity for a weight management program.

However, the study has some limitations. First, we did not have information on fitness facility prices, the features or quality of fitness facilities or parks, sidewalk availability or other pedestrian infrastructure, or social environment features. Second, we studied the residential environment; the broader environment where people conduct activities and spend time may matter more (Burgoine et al., 2014; Zenk et al., 2011). Third, estimated treatment effects in our study could still be biased by unmeasured, time-varying factors (e.g., individual SES for which data are not uniformly collected in the VA) that are correlated with BMI if they are also more prevalent among MOVE! participants than comparisons. Fourth, because veterans and VA users in particular differ from the general U.S. population, our results may not be generalizable to the overall U.S. adult population.

5. Conclusions

Why are some people who engage in weight management interventions successful at weight loss and weight loss maintenance? We postulated the impact of the MOVE! program depended on the extent to which the program complemented or substituted for the built environment where the patient lived. Our results do not suggest the MOVE! program complements or substitutes for residential access to walkable space or recreational places. Nonetheless, the link between behavioral interventions and environmental context warrants investigation in other interventions and samples (Saelens et al., 2018; Zenk et al., in press).

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2019.105776.

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