Does light rail transit increase physical activity?

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ABSTRACT

Moderate walking between home and transit stops can be a significant portion of daily physical activity. Yet, we know little about the role of public transit in promoting physical activity at the neighborhood level. Using a pre-post treatment-control research design, we examine whether new Expo light rail transit has any impact on physical activity outcomes among residents of a low-income neighborhood in south Los Angeles. We hypothesize that physical activity gain varies by proximity to transit stations, transit trip frequency, and past behavior. The data consist of two waves of longitudinal samples collected about 6 months before and after the implementation of new Expo light rail transit in Fall 2012. Based on the 82 repeated samples across the two waves, we obtained travel behavior and physical activity data through a travel diary, GPS logger, and accelerometer for a 7-day period. The results suggest that proximity to transit has a complex association with physical activity. Taking more bus transit trips positively affects physical activity. Also, individual characteristics determine the extent to which physical activity increases. Further, past physical activity levels play a key role in moderating the effect of the Expo Line on later physical activity levels of the residents living near the Expo Line. The implication is that the health impact of transit investments at the neighborhood level is complex and potentially operates through mediators/moderators, such as personal characteristics and past behavior. Our findings indicate that health impact assessments of transit investments should be comprehensive, possibly incorporating individual and behavioral factors in order to account for this complex relationship.

INTRODUCTION

Physical inactivity is a major concern in urban planning and public health. It is not only a major risk factor for obesity, but also for a variety of chronic diseases, such as coronary heart disease, type 2 diabetes, and breast and colon cancers (Lee et al. 2012). A growing body of research suggests that physical inactivity or a sedentary lifestyle is largely influenced by how people travel and exercise on a daily basis (Eheman et al. 2012; Frank, Andresen, and Schmid 2004). Many people cannot spare extra time to meet their daily physical activity levels of at least 30 minutes of moderate-intensity activity. Thus, an effective way to meet the daily physical activity recommendation is to integrate active travel, such as walking and biking, as part of people's daily routine.

Public transportation can potentially offer an opportunity to increase physical activity, especially by walking to and from transit stops. Even though these walking trips are short, when added together, they may contribute to substantial amount of physical activity. Previous studies have found that transit users generally walk more (Besser and Dannenberg 2005; Lachapelle et al. 2011; Edwards 2008), burn more calories (Morabia et al. 2010), and can lose more weight (Lindström 2008). However, other studies have also found some mixed results. Wilson et al. (2011) found that proximity to transit did not significantly affect transit use or physical activity. Also, personal characteristics, like gender and weight status have different impacts on transit use and physical activity participation (Wen et al. 2011; Tucker et al. 2013). Some researchers have also pointed out that people may maintain a physical activity budget (Rodríguez, Khattak, and Evenson 2006), substituting transport walking with recreational walking, making total physical activity unchanged regardless of different neighborhood-level interventions aimed at influencing travel behavior.

Despite many debates on the relationship between transit and physical activity, public transportation projects increasingly consider health as one of the criteria for project evaluation (Stokes, MacDonald, and Ridgeway 2008; Topalovic et al. 2012). However, the gaps in the previous research undermine our ability to formulate useful policy recommendations. Major issues in previous research include: 1) overwhelming use of cross-sectional data; 2) limited theoretical foundation; and 3) lack of micro-level data linking daily travel patterns and physical activity outcomes. This research attempts to address these gaps through an experimental framework by investigating changes in travel and physical activity outcomes before and after the Expo Line, a new light rail transit service in Los Angeles. Based on the previous literature, we formulate three hypotheses regarding the effect of light rail transit, and test these hypotheses through a longitudinal research framework.

PREVIOUS RESEARCH AND GAPS

Previous research investigating the relationship between transit and physical activity is lacking in three aspects. First, most physical activity studies rely heavily on cross-sectional data, and lack a sound methodological framework to address residential selection bias. The cross-sectional framework offers limited understanding of how individual travel behavior and physical activity change when residential location and the built environment, such as transit infrastructure, change (Boarnet 2011). Even with transit users, it is hard to draw a firm conclusion whether access to and availability of transit service lead to more transit use because of endogeneity with other unobserved characteristics. In recent years, residential self-selection has been the most debated topic in travel behavior research (Cao, Mokhtarian, and Handy 2009). Residential selection bias suggests that people may ride more transit because of their travel preference, not because of access to transit service or transit supply in their neighborhoods.

We consider new Expo Line service as a natural experiment to investigate before-and-after changes in physical activity of residents living near the transit stations (experimental group) vs. the residents farther from the stations (control group). We seek to minimize residential selection bias by assigning experimental and control groups within a relatively short period of time (six months) before and after the opening of the new Expo Line. This allows little time for new residents to move in or move out in response to the new rail transit, allowing us to measure a pure "transit effect" of new rail service on the travel behavior of pre-existing residents.

Second, public transit service does not guarantee physical activity; it provides opportunities for physical activity. People who take transit may walk more and thus be physically active than car drivers (Lachapelle and Noland 2012; Morabia et al. 2010). However, people rarely take public transit in order to gain more physical activity. People take transit to get to certain places, and physical activity gain occurs in the process. Thus, utility or disutility associated with certain transportation modes affects individual travel decisions. In this sense, the link between public transit use and physical activity lies in the classic utility maximization framework which considers a broad range of factors in determining travel behavior. Therefore, the utility gained from walking to transit varies from person to person, and satisfaction/dissatisfaction from that behavior depends on various factors and personal traits. For example, interpersonal differences, such as gender, race, income status, and health conditions, may play a significant role in determining the utility of transit trips, thus influencing walking behavior to transit stops and subsequent physical activity gain. Our research uses the best-possible empirical data from panel samples to examine the health-related impact of transit service. We adopt longitudinal modeling approach to help understand the causal mechanism between transit service and physical activity.

Third, there is a lack of comprehensive micro-level data linking travel behavior and physical activity outcomes. On the one hand, many public health and behavior studies focus on personal and psychosocial determinants of physical activity, either for transport or leisure, while controlling for physical environmental factors (Sallis 2009; Pikora et al. 2003; Panter and Jones 2010). On the other hand, most urban planning and transportation studies focus on travel behavior, particularly for transport, and built environmental correlates of physical activity while controlling for other personal and socioeconomic factors (Frank et al. 2007; Handy et al. 2002; Khattak and Rodriguez 2005). Our research aims to bring together all the relevant factors involving personal, psychosocial, behavioral, and built environment determinants of physical activity behavior in an experimental-control research design.

This study is part of the larger Expo Line research project, a multi-year longitudinal research program investigating before-and-after impacts of the Expo light rail transit investment in Los Angeles. Using the two waves of data collected from this project thus far, we address gaps in the previous studies with two different analytical approaches: difference-in-differences (DID) and a lagged dependent variable (LDV) model. We believe these longitudinal models, combined with the richness of data obtained through the ongoing Expo Line project, allow us to overcome a common threat to causal inference while making a stronger assertion regarding the link between transit service and physical activity.

RESEARCH QUESTIONS AND HYPOTHESES

The questions we ask in this paper are three-fold: a) do persons' physical activity levels change before and after a new light rail transit implementation?; b) does travel behavior, transit trip frequency in particular, influence individual physical activity levels?; and c) is there any influence of predisposed personal and behavioral characteristics on physical activity change in response to new light rail service? Based on these research questions, we formed the following three hypotheses to explore the causal mechanism between public transit and physical activity.

H_1: Environmental exposure hypothesis

We first hypothesize that people living near light rail stations become more physically active than those living farther away. This hypothesis is based on research examining the relationship between land use and travel behavior. In general, a half-mile boundary is considered a typical catchment area for public transportation because people are willing to walk to transit stops within this boundary (Ewing 1999). Thus, this hypothesis tests whether exposure to new light rail within ½ mile of one's home leads to more physical activity.

H_2: Transit use hypothesis

The second hypothesis tests whether people who use more transit become more physically active. This hypothesis focuses on the relationship between transit use and physical activity. Previous studies have shown that transit users generally maintain higher physical activity levels than those who drive to work (Sahlqvist, Song, and Ogilvie 2012; Wener and Evans 2007). These studies indicate that an increase in active forms of travel to and from transit stops, such as walking and biking, largely contribute to higher physical activity. Therefore, regardless of whether individuals live close to a transit station or not, an increase in public transit use may lead to higher physical activity levels after the Expo line intervention.

H_3: Past behavior and personal characteristics hypothesis

The third hypothesis focuses on the influence of past behavior and personal characteristics on physical activity participation. We hypothesize that, when controlling for personal differences, past physical activity behaviors determine later physical activity behaviors. Studies have shown that past behavior is related with habit formation and can attenuate intentions to engage in physical activity (Hagger, Chatzisarantis, and Biddle 2001; Ajzen 2002). We expect that physically active people continue to stay active, while physically inactive people tend to remain inactive. Thus, the effect of new light rail line will be moderated by past behavioral conditions as well as personal characteristics.

DATA AND METHODS

Study Area and Research Design

The context of this study is a neighborhood along the Exposition Line (Expo Line), a light rail transit line in Los Angeles that extends south and west from downtown Los Angeles, reaching downtown Santa Monica upon completion. The Phase I of the Expo Line connecting downtown Los Angeles and Culver City was completed in early 2012, and has been in operation since April 2012. Using this new light rail line as a natural experiment, we use a quasi-experimental research design to collect before/after physical activity and travel data for households from "experimental" neighborhoods along the Expo Line and comparable nearby "control" neighborhoods, not receiving transit service enhancements. The experimental area, receiving the light rail line "treatment", was based on a half mile radii around the six westernmost Expo Line Phase I stations (Figure 1). The half mile area was chosen to correspond with evidence in the literature on the effect of rail transit on travel behavior.

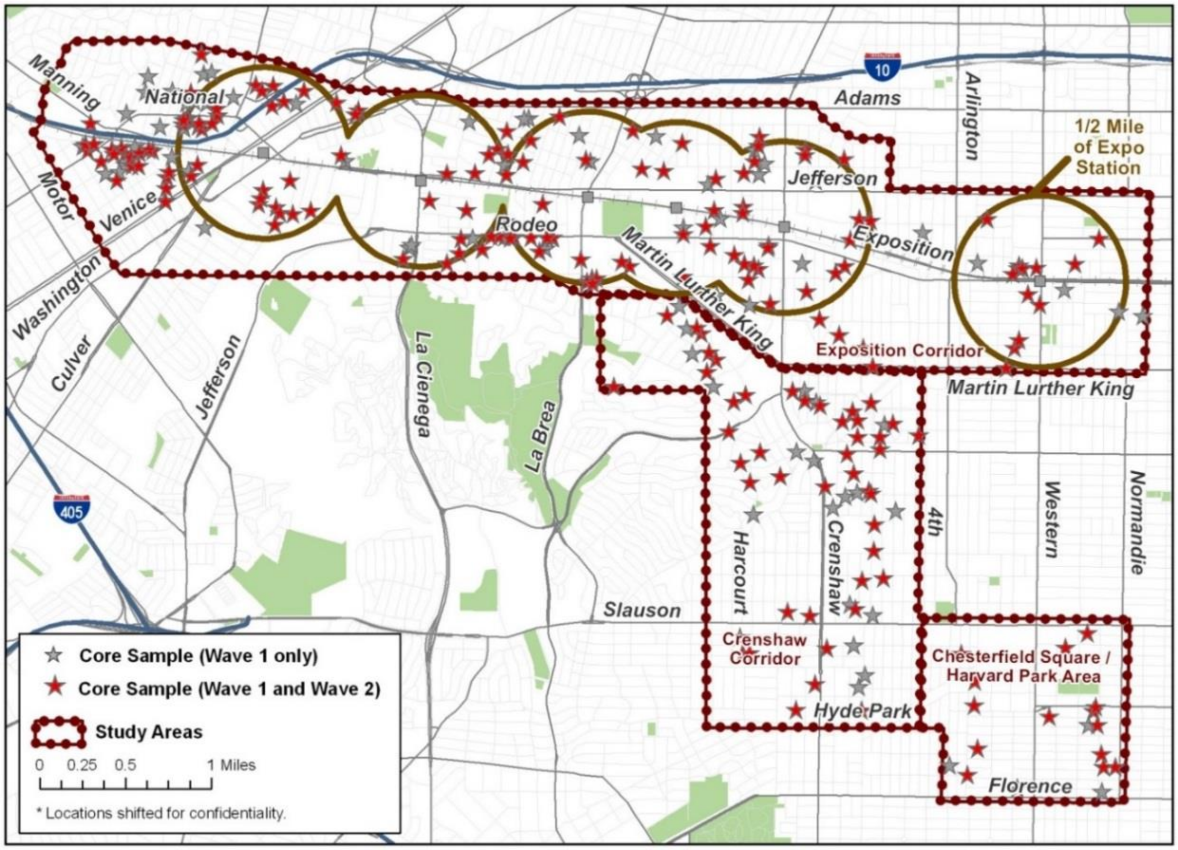

Figure 1: Map of Expo study area

Data Collection and Preparation

The data consist of two waves of longitudinal samples collected in fall 2011 and fall 2012, respectively. The Expo light rail opened in April of 2012, and the first wave contains before-opening data while the second wave contains the after-opening data. Both waves contain comprehensive information regarding travel patterns, physical activity, and real-time locational information for 143 individuals in wave 1 and 106 individuals in wave 2. In both waves, the main respondents completed an extensive questionnaire related to socio-economic status, typical travel patterns, attitudes and perceptions, and fear of crime. They also completed a 7-day travel log, and carried a GPS-based logger and accelerometer for a 7-day period.

Our main dependent variable is average daily moderate-to-vigorous physical activity (MVPA) minutes, which is defined as raw accelerometer counts exceeding 1952 counts/minute according to the most commonly used cut points (Freedson, Melanson, and Sirard 1998). Participants' acceleration was measured using an Actigraph™ accelerometer (Model GT1M). They wore the device on the right hip on a nylon belt around the waist during waking hours for seven days. In-house R code and MeterPlus software were used to screen and clean the raw Actigraph data; to identify participant days for the analysis; and to generate measures for average daily MVPA. For data cleaning, we tested five different criteria[1] to determine valid days—these criteria were adapted from Masse et al (2005). The different criteria we

[1] Criteria 1: 8 hours of valid wear-time excluding 20 minutes of continuous zeros per hour; Criteria 2: 10 hours of valid wear-time excluding 20 mins of continuous 0s per hour; Criteria 3: 8 hours of valid wear-time excluding 60 mins of continuous 0s per hour; Criteria 4: 10 hours of valid wear-time excluding 60 mins of continuous 0s per hour; Criteria 5: 9 hours of valid wear-time excluding 60 mins of continuous 0s per hour.

tested yielded similar results in all outcome measures with correlation over 90%. Given the high correlation among different criteria, we decided to use 8 valid hours instead of the commonly used 10 valid hours because we lost more than 12% of sample when moving from 8 hours to 10 hours. Thus, the final data reduction scheme included: i) defining "non-wear" time as having consecutive zero values for 60 minutes; ii) classifying a valid hour by excluding this "non-wear" time; iii) classifying a valid day by having 8 or more valid hours; and iv) selecting participants with at least three valid days as the final sample.

The independent variables include two treatment conditions: i) treatment effect of transit exposure defined as a dummy variable indicating whether the subjects live within a half mile boundary of the six westernmost Phase I Expo light rail stations, and ii) treatment effect of increased transit use defined as a dummy variable indicating 1 if transit trip frequency increased from wave 1 to wave 2; and 0 otherwise. Other covariates include personal characteristics, such as gender, age, body mass index (BMI), and knowledge about the surrounding transport environment.

Analysis Strategy

Our analysis strategy involves two approaches: a difference-in-differences (DID) model and a lagged dependent variable (LDV) model. The DID approach examines the effect of light rail on physical activity without considering time-stable covariates, such as sex and income. This model allows for detecting the treatment effect of light rail exposure and treatment effect of increased transit use before and after the Expo line intervention. The LDV approach allows for estimating time-invariant covariates as well as the effect of past behavior and baseline physical activity levels in wave 1.

Difference-in-Differences (DID) approach:

$$Y_{it} = \beta_0 + \beta_1 X_i + \beta_2 T_t + \beta_3 (X_i \times T_t) + e_{it}$$

Where,

Y_{it} is a physical activity outcome variable for individual i at time t
β_0 is the constant
β_1 is the effect of living within the experimental area (1/2 mile from a station) before and after the rail opening
β_2 is the time effect (pre / post effect of light rail construction) for both the experimental and control groups
β_3 is the effect of the treatment on the treated, i.e. the effect of living in the experimental area after the light rail opened
X_i is the group dummy variable, 0 for control group; 1 for experimental group
T_t is the time dummy variable, 0 for pre-treatment period; 1 for post-treatment period
e_{it} is the error term

The DID model is used for testing the first and the second hypotheses. We expect β_3 to be positive and significant if the new light rail has an effect on physical activity on residents near the stations (experimental group). This model can be further expanded to test the second hypothesis. If we consider increased transit use as a treatment, then β_3 indicates the effect of increased transit use on physical activity outcomes. Because this model differences out any time-invariant variables, it cannot be used to test the third hypothesis, which includes relatively time constant measures, such as sex and income. Thus, we employ the LDV model to examine the effect of time-invariant factors as well as past physical activity behavior.

Lagged Dependent Variable (LDV) approach:

$$Y_{i,t+1} = \beta_0 + \beta_1 Y_{i,t} + \beta_2 X_i + \beta_3 (Y_{i,t} \times X_i) + \sum_{j=1}^{n} \gamma_j Z_{ijt} + e_{it}$$

Where,

$Y_{i,t+1}$ is a physical activity outcome variable for individual *i* at time *t+1*
$Y_{i,t}$ is a physical activity outcome variable for individual *i* at time *t*
X_i is the group dummy variable, 0 for control group; 1 for experimental group
Z_{ijt} is the personal characteristic *j* (covariate) of individual *i* at time *t*
β_0 is the constant
β_1 is the effect of lagged dependent variable
β_2 is the effect of the treatment
β_3 is the effect of interaction between lagged dependent variable and treatment condition
γ_j is the effect of covariate *j*
e_{it} is the error term

The LDV model tests all three hypotheses and allows us to examine the effect of time-invariant measures. This model estimates physical activity levels in wave 2 by including physical activity levels in wave 1 ($Y_{i,t}$) as a predictor variable. β_2 is the experimental effect of living near the light rail station. β_3 indicates the moderated treatment effect, represented as an interaction between the previous physical activity level and the dichotomous treatment condition (control vs. experimental group). γ_j indicates the effects of covariate *j* at time *t*, such as transit use, gender, and transport knowledge. Other time-constant measures can be included in the model; but, we mainly include three control variables (age, sex, and BMI) for building a parsimonious model.

RESULTS AND DISCUSSION

Descriptive Results

Table 1 shows the descriptive statistics for all the sociodemograpic variables. In general, the control group is slightly younger, more overweight, less educated, and has more cars than the experimental group. The control group has more low income and African-American residents than the experimental group. The experimental group has higher baseline physical activity levels than the control group.
However, the differences between the two groups are not statistically significant, except for the number of cars.

Table 1: Baseline demographics and physical activity between control and experiment groups

Variables		Control (*N*=44)	Experimental (*N*=38)	Sig.	
Age	Mean	54.89	49.26	0.068	·
	SD	12.29	14.83		
Sex (male=1)	Mean	0.34	0.34	0.991	
	SD	0.48	0.48		
BMI	Mean	30.45	29.19	0.596	
	SD	7.43	12.49		
Health status (1-4)	Mean	1.82	1.68	0.342	
	SD	0.54	0.70		
Number of cars	Mean	1.70	1.24	0.026	*
	SD	1.05	0.82		
Household Income[a]	< 15k	18%	19%	0.896	
	15k - 35k	32%	22%		
	35k - 55k	11%	8%		
	55k - 75k	11%	14%		
	75k - 100k	14%	19%		
	> 100k	14%	19%		
Race / Ethnicity[a]	White	23%	29%	0.251	
	Black	64%	45%		
	Asian	2%	13%		
	Hispanic	7%	5%		
	Native Indian	0%	0%		
	Other/multi	5%	8%		
Education[a]	< 12th grade	5%	8%	0.318	
	High school	9%	0%		
	Some college	32%	21%		
	Associate	14%	18%		
	Bachelor	27%	29%		
	Post graduate	14%	24%		
Baseline MVPA	Mean	20.07	23.55	0.363	
	SD	17.79	16.36		

t-test used for significance; [a]: fisher test used for significance
· <0.10, * < 0.05, ** < 0.01, *** < 0.001, two-tailed tests

Table 2 is summary statistics for self-report travel outcomes, including vehicle miles traveled (VMT). The control group generally increased car travel, but the experimental group decreased car use after the opening of the Expo Line. VMT increased in the control group but decreased in the experimental group. For other modes, both control and experimental groups increased train and bus trips, and minutes in walking and bicycling also increased. However, the difference in travel outcomes between wave 1 and wave 2 were not statistically significant, except for the daily train trips, which is marginally significant at the 10% level.

Table 2: Self-reported travel behavior outcomes before and after the new light rail

Variables[a]		Control (*N*=44)			Experimental (*N*=38)		
		Wave 1	Wave 2	Sig.	Wave 1	Wave 2	Sig.
Daily car trips	Mean	3.29	3.63	0.529	3.71	3.31	0.488
	SD	2.36	2.61		2.56	2.51	
Daily train trips	Mean	0.04	0.07	0.719	0.04	0.15	0.090 +
	SD	0.15	0.41		0.20	0.35	
Daily bus trips	Mean	0.47	0.26	0.222	0.45	0.52	0.758
	SD	0.99	0.57		0.93	1.09	
Daily walk minutes	Mean	20.00	31.15	0.347	20.72	24.64	0.696
	SD	26.05	71.55		37.68	46.63	
Daily bicycle minutes	Mean	1.34	1.72	0.795	3.99	2.64	0.613
	SD	6.64	6.92		14.81	6.74	
Household VMT (7 days)	Mean	34.74	36.58	0.757	32.38	27.88	0.518
	SD	20.73	29.15		29.56	24.91	
Household VMT (Weekday)	Mean	25.54	35.00	0.221	31.77	28.98	0.735
	SD	22.15	40.93		30.89	34.50	
Household VMT (Weekend)	Mean	38.45	37.21	0.854	32.60	27.44	0.529
	SD	23.17	33.06		36.46	27.00	

[a]: t-test used for significance; + <0.10, * < 0.05, ** < 0.01, *** < 0.001, two-tailed tests

Table 3 shows physical activity outcomes. The experimental group decreased physical activity across all levels. The control group actually increased hard activity. It is difficult to tell if this difference is meaningful because none of the measures are statistically significant. The fact that the experimental group decreased physical activity in wave 2 is counter intuitive. At least at the aggregate level, the result does not appear to support the environmental exposure hypothesis, implying that there is little treatment effect of living near the transit stations. Even if there is any treatment effect, it is likely to be moderated by other factors, either observed or unobserved.

Table 3: Accelerometer-based physical activity outcomes before and after the new light rail

Variables[a]		Control (*N*=44)			Experimental (*N*=38)		
		Wave 1	Wave 2	Sig.	Wave 1	Wave 2	Sig.
Raw counts	Mean	205,475.55	201,532.22	0.846	228,170.33	215,642.65	0.427
	SD	100,913.29	89,055.97		74,849.93	61,048.21	
Daily sedentary minutes	Mean	512.98	510.41	0.924	484.99	505.91	0.346
	SD	123.85	129.43		90.99	100.87	
Daily light minutes	Mean	260.83	264.57	0.835	271.01	268.29	0.861
	SD	84.85	83.47		66.21	69.16	
Daily moderate minutes	Mean	19.88	18.42	0.698	22.78	21.62	0.739
	SD	17.76	17.63		16.11	14.15	
Daily hard minutes	Mean	0.19	0.31	0.570	0.76	0.42	0.503
	SD	0.62	1.27		2.83	1.40	
MVPA[b]	Mean	20.07	18.73	0.725	23.55	22.04	0.674
	SD	17.79	17.94		16.36	14.68	
	Min	0	0.71		1.43	1.14	
	Max	96.00	79.60		74.86	47.80	

[a]: t-test used for significance; + <0.10, * < 0.05, ** < 0.01, *** < 0.001, two-tailed tests
[b] MVPA (moderate and vigorous physical activity) is a common measure of physical activity which combines minutes in moderate and hard physical activity. Note that only one subject in control group has 0 MVPA in wave 1.

Difference-in-Differences (DID) Model Results

Based on the descriptive results, we tested our hypotheses using two different approaches: difference-in-differences (DID) and lagged dependent variable (LDV) models. For the DID approach, we examined the treatment effect of living near the transit (hypothesis 1) and the effect of increasing transit use (hypothesis 2). DID 1 in Table 4 shows the treatment effect of living near the transit stations. As expected from the descriptive analysis, neither time nor the experimental effect was statistically significant. Further, the DID estimator (Time x Experimental group) has a negative coefficient, but it is not statistically significant.

Table 4: DID models of average daily MVPA minutes

Variables	DID 1		DID 2		DID 3		DID 4	
	Estimate	t-value	Estimate	t-value	Estimate	t-value	Estimate	t-value
Intercept	20.07	7.91 ***	21.23	10.49 ***	20.30	10.18 ***	20.39	9.92 ***
Time[a]	-1.35	-0.38	-3.95	-1.38	-2.44	-0.86	-4.07	-1.40
Experimental[b]	3.48	0.93						
Time x Experimental	-0.16	-0.03						
Increased bus trips[c]			2.43	0.50			-0.71	-0.14
Increased train trips[c]					9.03	1.75 ·	9.31	1.71 ·
Time x Increased bus			14.38	2.10 *			13.92	1.93 ·
Time x Increased train					6.68	0.92	1.36	0.18
N	160		156		156		154	
R^2	0.012		0.075		0.075		0.114	
Adjusted R^2	-0.006		0.057		0.057		0.085	

Dependent variable: Average daily MVPA minutes in wave 1 and wave 2
[a] 0 = wave 1, 1 = wave 2; [b] 1 = within ½ mi, 0 = otherwise; [c] 1 = increase, 0 = otherwise
· <0.10, * < 0.05, ** < 0.01, *** < 0.001, two-tailed tests

We plotted the daily average MVPA minutes by distance from transit stations. The effect of living near the Expo Line on physical activity is likely to be complex, possibly following a non-linear distance gradient from stations. Figure 2 compares the effect of transit exposure on physical activity patterns before and after the light rail construction. The y-axis is the average daily MVPA minutes, and the x-axis represents distance from home to the nearest light rail transit station. In wave 1, there seems to be no apparent pattern, representing a before-treatment condition. In wave 2 which represents an after-treatment condition, the gradient effect seems to follow a non-linear function. The gradient effect on physical activity is more pronounced between 3/8th of a mile and 5/8th of a mile from the station, which we call the "effective range". The half-mile boundary falls within this range, but the effect is not linear as we had previously expected. This may reflect that for persons living near the light rail station (e.g. less than 3/8th of a mile) the new rail transit might have reduced the distance required to walk to transit service. Beyond distances of 5/8th of a mile, rail transit access may not matter if persons will not walk to transit at those distances or farther. Hence the new light rail may be associated with increased physical over an effective distance range that approximates 3/8th to 5/8th of a mile, possibly due to increased walking to transit for persons who live within that distance range from new stations. Yet, note that the changes in the distance pattern shown in Figure 2 are all within the confidence intervals, and hence this speculation is based on patterns that likely do not statistically differ between Wave 1 and Wave 2.

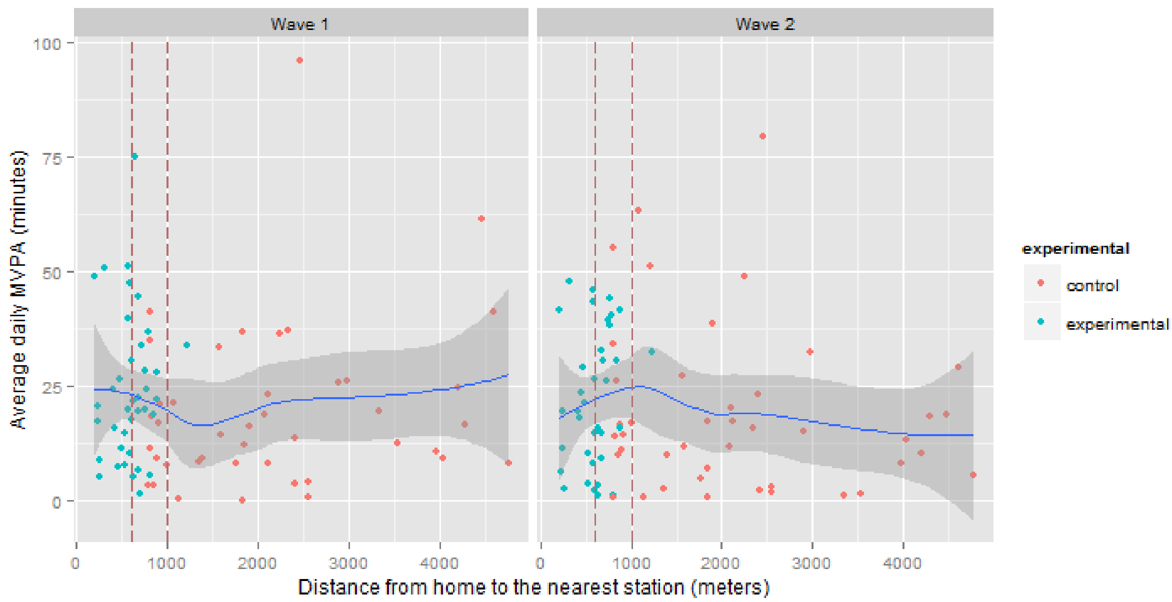

Figure 2: Distance to the nearest station by MVPA minutes in wave 1 and wave 2
*The dotted lines indicate the effective range (between 3/8th of a mile and 5/8th of a mile)

DID 2 and DID 3 examine a treatment effect of increased transit use. We included two dummy variables to indicate any increase in bus trips or train trips from wave 1 to wave 2. (1 indicates increased trips; 0 indicates the same or decreased trips.) Because of the small number of people who actually increased transit trips from wave 1 to wave 2[2], we may not see statistically strong treatment effect. However, we did observe a treatment effect of increased bus trips. The coefficient of the treatment (Time x Increased bus trips) is statistically significant at the 5% level, and the effect size is quite large. For persons who increased bus trips, those subjects had 14.38 minutes more MVPA on average. In terms of train trips, the treatment effect (Time x Increased train trips) is not significant.

Overall, the DID models indicate that the original hypothesis of environmental exposure did not hold. The treatment effect of being close to transit did not produce any statistically significant result. However, subjects who actually used more bus transit did increase physical activity, showing the treatment effect of increasing bus trips from wave 1 to wave 2. This finding supports the Hypothesis 2 that taking more bus transit could increase physical activity.

Lagged Dependent Variable (LDV) Model Results

Even though the first hypothesis did not hold, the LDV models support the second and third hypotheses. Table 5 shows the LDV models where MVPA minutes in wave 2 were regressed on MVPA minutes in wave 1 and other covariates. LDV 1 is the base model with core demographics: age, sex, and BMI. The coefficient on $MVPA_1$ is positive and significant at the 0.1% level. This implies past physical activity conditions significantly affect later conditions. The coefficient on gender is also positive and statistically significant at the 1% level, implying that males had 8.27 minutes of physical activity more than females.

LDV 2 is a slightly more complex model than LDV 1, partly because it interacts the previous (Wave 1) physical activity level with the experimental effect. Overall, proximity to the light rail is positive and significant (10.46). This means that people who live near the new rail stations were generally

[2] 14 people increased train trips; 16 people increased bus trips; 8 people increased both bus and train trips from wave 1 to wave 2.

more physically active than people living farther away. Yet, the treatment effect of the Expo line is likely to be moderated by previous physical activity level. The interaction term is highly significant but has a negative coefficient (-0.47). Being close to the light rail stations has a negative effect on people who were more physically active previously, or conversely light rail transit access has a larger positive effect on physical activity gain among residents who were previously the least physically active. In addition, age in years is significant and negative (-0.22).

Table 5: LDV models of average daily MVPA minutes

Variables	LDV 1		LDV 2		LDV 3		LDV 4	
	Estimate	t-value	Estimate	t-value	Estimate	t-value	Estimate	t-value
Intercept	16.90	2.03 *	15.16	1.89 ·	16.96	2.44 *	3.16	0.41
$MVPA_1$	0.51	5.86 ***	0.69	6.50 ***	0.70	7.57 ***	0.74	8.47 ***
Experimental[a]	0.15	0.05	10.46	2.22 *	8.36	2.04 *	9.83	2.55 *
$MVPA_1$ x Experimental[a]			-0.47	-2.76 **	-0.53	-3.63 ***	-0.57	-4.16 ***
Age	-0.19	-1.79 ·	-0.22	-2.13 *	-0.29	-3.14 **	-0.24	-2.75 **
Sex[b]	8.27	2.65	9.72	3.20 **	7.74	2.90 **	7.61	3.05 **
BMI	-0.02	-0.12	-0.05	-0.32	-0.03	-0.23	-0.03	-0.22
Increased train trips[c]					4.65	1.20	1.42	0.38
Increased bus trips[c]					15.70	4.53 ***	13.62	4.13 ***
Knowledge about transit service[d]							2.17	3.34 **
N	74		73		70		69	
R^2	0.425		0.480		0.629		0.680	
Adjusted R^2	0.387		0.437		0.586		0.638	

Dependent variable: MVPA minutes in wave 2

[a] 1 = within ½ mi, 0 = outside ½ mi; [b] 1 = Male, 0 = Female; [c] 1 = increase, 0 = otherwise; [d] 1 = lowest, 7 = highest

· <0.10, * < 0.05, ** < 0.01, *** < 0.001, two-tailed tests

LDV 3 and 4 test the effects of transit use and self-reported transit knowledge (Hypotheses 3 and 4). In LDV 3, subjects who increased bus trips from wave 1 to wave 2 were significantly more physically active than those who decreased or maintained the same bus trip frequency. The coefficient has a large effect size and is highly significant at the 0.1% level (15.70 minutes). This is a substantial physical activity gain, which could lead to meaningful health benefits. This result is consistent with the previous studies suggesting a close relationship between bus trips and physical activity (Lachapelle and Noland 2012; Besser and Dannenberg 2005). Subjects who took more train trips also increased physical activity, but the coefficient is not statistically significant.

LDV 4 examines whether transit knowledge increases physical activity participation. A 1-point rise in knowledge about transit service (a scale of 1 to 7) increases MVPA minutes by 2.17 minutes. While different from transit knowledge, other studies have found that psychological satisfaction and a positive evaluation of service quality help maintain transit use, and subsequently leads to more physical activity (Brown, Werner, and Kim 2003; Hoehner et al. 2005).

Overall, all four LDV models have good model fits, suggesting that a lot of variation in average MVPA minutes can be explained by the suggested specifications in the model. Given high correlation between physical activity levels in wave 1 and wave 2, what is more important than the absolute goodness of fit measure is the relative change in model fit. The model fit improved more than 63% from model 1 to model 4. This improvement suggests that inclusion of the interaction term between previous physical activity and proximity to transit service, increased transit use, and transit knowledge can explain much variability in the probability of average daily MVPA minutes. Because of the small sample size, however, explanatory power of the models could be limited, and may not be representative of the travel and physical activity patterns in the general population.

Robustness check of the results

In our longitudinal sample, we observed large changes in physical activity levels for a few individuals. To account for these influential observations, we further developed three criteria to determine whether our model results are robust to removing influential observations from the full data set. The first criterion is to use all observations without making any assumptions about the influential observations. The second criterion is to drop all observations when daily average MVPA minutes change by more than 60 minutes a day. This criterion was to remove extreme outliers, and only one observation was removed from the sample. The third criterion is to drop all observations when the percentage change in daily average MVPA minutes between the two waves is higher than 15%. We chose this cut-off point because visual examination of the data indicated that this threshold identified potential outliers.

Table 6 and Table 7 show the DID results after removing the influential observations using these exclusion criteria. Table 6 compares the DID 1 results which examine the treatment effect of living near the Expo Line. Table 7 compares the DID 4 results with test the treatment effect of increased bus use. In all DID models, the results appear to be robust with or without the influential observations. The coefficients and the standard error remain relatively the same regardless of different criteria.

Table 6: Comparison of DID 1 results after removing influential observations

Variables	DID 1 (criterion 1)			DID 1' (criterion 2, exclude observations > 60 minutes +/- MVPA change)			DID 1" (criterion 3, exclude observations > 15% +/- MVPA change)		
	Estimate	t-value		Estimate	t-value		Estimate	t-value	
Intercept	20.07	7.91	***	20.07	8.15	***	20.08	8.04	***
Time[a]	-1.35	-0.38		-1.35	-0.39		-0.95	-0.27	
Experimental[b]	3.48	0.93		2.089	0.573		2.66	0.72	
Time x Experimental	-0.16	-0.03		1.792	0.348		0.59	0.11	
N	160			158			154		
R^2	0.012			0.009			0.009		
Adjusted R^2	-0.006			-0.009			-0.011		

Dependent variable: Average daily MVPA minutes in wave 1 and wave 2
[a] 0 = wave 1, 1 = wave 2; [b] 1 = within ½ mi, 0 = otherwise
· <0.10, * < 0.05, ** < 0.01, *** < 0.001, two-tailed tests

Table 7: Comparison of DID 4 results after removing influential observations

Variables	DID 4 (criterion 1)			DID 4' (criterion 2, exclude observations > 60 minutes +/- MVPA change)			DID 4" (criterion 3, exclude observations > 15% +/- MVPA change)		
	Estimate	t-value		Estimate	t-value		Estimate	t-value	
Intercept	20.39	9.92	***	19.50	9.75	***	19.80	9.71	***
Time[a]	-4.07	-1.40		-2.94	-1.04		-3.22	-1.12	
Increased bus trips[b]	-0.71	-0.14		-0.07	-0.01		-0.29	-0.06	
Increased train trips[b]	9.31	1.71	·	9.87	1.88	·	9.68	1.84	·
Time x Increased bus	13.92	1.93	·	13.09	1.88	·	13.30	1.90	·
Time x Increased train	1.36	0.18		0.64	0.09		0.81	0.11	
N	154			152			148		
R^2	0.114			0.121			0.122		
Adjusted R^2	0.085			0.092			0.092		

Dependent variable: Average daily MVPA minutes in wave 1 and wave 2
[a] 0 = wave 1, 1 = wave 2; [b] 1 = increase, 0 = otherwise
· <0.10, * < 0.05, ** < 0.01, *** < 0.001, two-tailed tests

Table 8 compares the LDV 4 results with and without the influential observations. The experimental effect remains statistically significant with criterion 2, but the effect attenuates after applying criterion 3, making the treatment effect non-significant. Interestingly, coefficients and the standard errors for the interaction term ($MVPA_1$ x the experimental group), age, and sex all attenuate after removing influential observations. All other coefficients and the standard errors remain relatively similar across the models with different exclusion criteria.

In summary, the DID models are consistent regardless of different criteria being applied, but the LDV model results change depending on which criterion is applied. The exclusion criteria we developed are systematic but based on a visual inspection of the data, not necessarily grounded in any behavioral assumption. If drastic change in the MVPA levels is the result of measurement error, then it would be reasonable to choose the criterion 3. However, there is no reason to believe that more than 15% changes in MVPA minutes are considered erroneous measures as some people may undergo drastic changes in behavior, possibly due to major life events or change in health status.

Table 8: Comparison of LDV results after removing influential observations

Variables	LDV 4 (criterion 1)			LDV 4' (criterion 2, exclude observations > 60 minutes +/- MVPA change)			LDV 4" (criterion 3, exclude observations > 15% +/- MVPA change)		
	Estimate	t-value		Estimate	t-value		Estimate	t-value	
Intercept	3.16	0.41		4.08	0.55		1.34	0.19	
$MVPA_1$	0.74	8.47	***	0.73	8.75	***	0.74	9.25	***
Experimental[a]	9.83	2.55	*	6.64	1.68	·	3.87	1.00	
$MVPA_1$ x Experimental[a]	-0.57	-4.16	***	-0.38	-2.51	*	-0.30	-2.05	*
Age	-0.24	-2.75	**	-0.22	-2.58	*	-0.20	-2.43	*
Sex[b]	7.61	3.05	**	6.23	2.51	*	5.94	2.52	*
BMI	-0.03	-0.22		-0.04	-0.37		0.00	0.04	
Increased train trips[c]	1.42	0.38		0.49	0.13		0.51	0.15	
Increased bus trips[c]	13.62	4.13	***	13.12	4.12	***	13.03	4.29	***
Knowledge about transit service[d]	2.17	3.34	**	1.97	3.10	**	2.08	3.42	**
N	69			68			66		
R^2	0.680			0.701			0.732		
Adjusted R^2	0.638			0.661			0.696		

Dependent variable: MVPA minutes in wave 2
[a] 1 = within ½ mi, 0 = outside ½ mi; [b] 1 = Male, 0 = Female; [c] 1 = increase, 0 = otherwise; [d] 1 = lowest, 7 = highest
· <0.10, * < 0.05, ** < 0.01, *** < 0.001, two-tailed tests

We calculated a marginal effect of the treatment effect from model LDV4 on $MVPA_2$.[3] We compared the marginal effects using the different exclusion criteria (Table 9). Figure 3 shows the sensitivity of the different exclusion criteria on the magnitude of the marginal effect. The marginal effect of the treatment (the Expo Line) on MVPA in Wave 2 ($MVPA_2$) is positive only up to a certain point but negative after that. This changing sign means that those subjects with previous MVPA levels lower than a threshold value would increase later MVPA levels in wave 2. Conversely, those with previous MVPA levels higher than the threshold would decrease later MVPA levels in response to light rail. As shown in Figure 3, this threshold point varies by different criteria being applied. The threshold point is 17.21 for MVPA minutes in Wave 1 (baseline) for the criterion 1 (≈ 46th percentile); 17.29 for the criterion 2 (≈ 46th percentile); and 12.73 for the criterion 3 (≈ 36th percentile). Substantively, this suggests that the new Expo Line had a more positive effect on those who previously had a relatively low physical activity level (bottom 36th to 46th percentile range) in the experimental group than those with higher physical activity levels.

[3] The marginal effect is calculated using this formula: $\frac{\partial MVPA_2}{\partial \text{Experimental}} = \beta_2 + \beta_3 MVPA_1$, where β_2 is the coefficient on Experimental and β_3 is the coefficient on the interaction term (Experimental x $MVPA_1$).

Table 9: Sensitivity of the LDV results with and without influential observations

Percentile	LDV 4 (Criterion 1)			LDV 4' (Criterion 2)			LDV 4" (Criterion 3)		
	MVPA1	MVPA2	Marginal Effect	MVPA1	MVPA2	Marginal Effect	MVPA1	MVPA2	Marginal Effect
0.01	0.27	0.81	9.67	0.27	0.81	6.54	0.26	0.81	3.79
0.05	3.29	1.17	7.95	3.29	1.29	5.38	3.41	1.67	2.83
0.25	9.04	8.21	4.67	9.00	8.33	3.18	9.07	8.74	1.11
0.50	18.83	15.86	-0.93	18.67	16.00	-0.53	18.67	16.00	-1.81
0.75	28.29	30.30	-6.32	27.86	30.67	-4.06	28.14	29.93	-4.68
0.95	50.71	48.94	-19.12	49.00	49.00	-12.18	49.18	49.20	-11.08

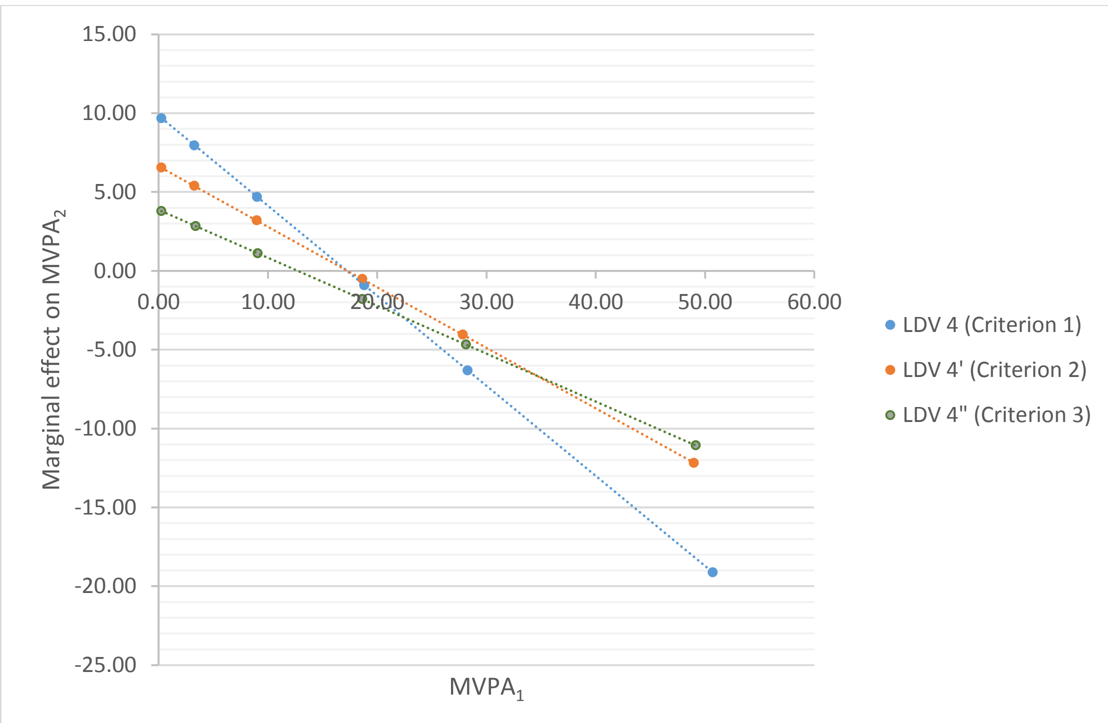

Figure 3: Sensitivity of the marginal effect of the interaction term (Experimental x MVPA1) on $MVPA_2$

Given this more nuanced effect of the Expo Line, we developed separate LDV models to test the different marginal effect of the treatment effect. To correctly identify the contrasting effect of low vs. high MVPA levels, we created a dummy variable indicating whether the subjects have lower (dummy = 1) or higher (dummy = 0) MVPA levels in wave 1 compared to the identified thresholds. The rest of the specification is the same as the previous LDV 4 model. See note "a" in Table 10 for $MVPA_1$ thresholds for the dummy variable.

Table 10 shows the result of the modified LDV models with the dummy variable and the new interaction term. Unlike the previous LDV models, the experimental variable and the interaction term remain statistically significant even after removing the influential observations (third column). Looking at the third column in this table, the coefficient for the $MVPA_1$ dummy variable is negative and highly significant. This suggests that regardless of being in the experimental group or not, any subjects with low baseline physical activity levels in wave 1 (bottom 36th percentile) are likely to decrease their daily physical activity levels from wave 1 to wave 2, as much as 21 minutes on average. The negative and significant coefficient for the experimental variable means the subjects in the experimental households are likely to decrease their daily physical activity levels by about 8 minutes on average. The interaction between the $MVPA_1$ dummy and the experimental variable is positive and marginally significant. The positive sign means that those experimental subjects in the bottom 36th percentile increased their daily physical activity levels from wave 1 to wave 2 by 11 minutes, after controlling for other factors. It should be noted that the coefficients for other variables, such as sex, transit trips, and transit knowledge, remain almost the same as the previous model in Table 8 (the third column).

In summary, the DID models were robust but the LDV models were not robust to the different exclusion criteria. However, further sensitivity analysis revealed that the inconsistent results of the LDV models may stem from varying degrees of individual response to the treatment. It is possible that the subjects with different baseline MVPA levels responded differently to the new the Expo Line service. The modified LDV models confirm this speculation that the Expo Line had more positive impact on people with lower baseline physical activity than those with higher physical activity level. The residents who live within the half mile of the Expo stations and are in the bottom 36th to 46th percentile of the baseline $MVPA_1$ levels increased their MVPA by approximately 3 and ½ to 6 minutes on average, holding everything else constant. The magnitude of this effect is not small given the commonly recommended 30 minutes of daily MVPA.

Table 10: Modified LDV model with $MVPA_1$ dummy variable

Variables	LDV 4 (Criterion 1)			LDV 4' (Criterion 2)			LDV 4" (Criterion 3)		
	Estimate	t-value		Estimate	t-value		Estimate	t-value	
Intercept	31.48	3.63	***	32.04	3.74	***	21.93	2.56	*
$MVPA_1$ dummy[a]	-20.59	-5.48	***	-20.56	-5.58	***	-21.31	-5.65	***
Experimental[b]	-10.87	-2.75	**	-8.47	-2.15	*	-7.60	-2.11	*
$MVPA_1$ dummy x Experimental	16.59	2.82	**	12.02	2.09	*	11.18	1.88	.
Age	-0.24	-2.23	*	-0.22	-2.10	*	-0.17	-1.58	
Sex[c]	8.18	2.69	**	6.84	2.25	*	6.81	2.30	*
BMI	-0.08	-0.61		-0.10	-0.72		-0.04	-0.28	
Increased train trips[d]	0.67	0.15		0.32	0.07		0.15	0.03	
Increased bus trips[d]	13.42	3.40	**	13.62	3.52	***	11.52	2.99	**
Knowledge about transit service[e]	2.01	2.58	*	1.87	2.44	*	2.75	3.47	***
N	69			68			66		
R^2	0.541			0.558			0.568		
Adjusted R^2	0.482			0.499			0.509		

Dependent variable: daily MVPA minutes in wave 2
[a] For criterion 1, 1 if $MVPA_1 < 17.21$, otherwise 0; For criterion 2, 1 if $MVPA_1 < 17.29$, otherwise 0; For criterion 3: 1 if $MVPA_1 < 12.73$, otherwise 0
[b] 1 = within ½ mi, 0 = outside ½ mi; [c] 1 = Male, 0 = Female; [d] 1 = increase, 0 = otherwise; [e] 1 = lowest, 7 = highest
• <0.10, * < 0.05, ** < 0.01, *** < 0.001, two-tailed tests

CONCLUSIONS

The primary goal of this paper was to examine whether light rail transit can increase physical activity. Our research design was based on the assumption that proximity to transit has a positive effect on physical activity. Thus, the treatment was a dichotomous measure: the experimental group representing the residents within half mile boundary of transit stops; and the control group representing those outside the half mile boundary. Based on the data we have, we cannot confidently say this is a good proxy measure for a treatment effect of transit exposure. The DID model revealed that the half-mile boundary has no statistically significant effect on physical activity. It appears that the impact of distance to transit follows a non-linear effect on physical activity. It is also possible that the half-mile boundary may be too strict a measure for a transit catchment area. Emerging evidence suggests that transit users may be willing to walk more than a half mile, and other personal and built environmental factors influence how much distance people are willing to walk (Ker and Ginn 2003; Canepa 2007). The new light rail may have attracted bus patronage both inside and outside the half mile boundary, resulting in a subsequent increase in bus ridership. The fact that increased bus trips contributed to an increase in MVPA levels from wave 1 to wave 2 supports this speculation that the new light rail may have generated more demand for bus transit, thereby increasing physical activity levels of those who took more bus trips. This finding is consistent with the previous studies that walking between home and transit stops accounts for non-trivial portion of physical activity (Lachapelle et al. 2011).

Another important finding is that personal characteristics and past behaviors are strong moderators of later physical activity and the light rail treatment effect. The LDV model results suggest that age, sex, and knowledge about transit service are strong predictors of physical activity. Failure to account for these important personal and psychosocial factors could lead to biased results. Likewise, past physical activity levels of an individual are important determinants of later physical activity levels. The marginal effect plot and the modified LDV model results reveal that a person's past physical activity levels moderate the effect of the light rail transit intervention. More specifically, the Expo Line has a positive effect on physical activity of those experimental subjects in the bottom 36th to 46th percentile of previous physical activity level. On the other hand, the same Expo Line has a negative effect on those in a higher percentile range. This finding suggests that past physical activity patterns could be a moderator of policy interventions that aim to encourage active travel. Further research needs to take into account both the possibility of non-linear gradient effects of distance to transit on physical activity, and personal and behavioral conditions of individuals.

Given these complex results, this research contributes to the current body of knowledge regarding the relationship between transit service and physical activity. This research uses a pre-post treatment-control research design to help understand the complex relationship between transit exposure, behavioral factors, and physical activity. To our knowledge, few studies have incorporated an experimental design to examine the effect of transit service on physical activity. The experimental setup allowed us to rule out any self-selection bias, a fundamental problem with previous research. It also allowed us make stronger statements regarding the causal effect of transit service on physical activity. The implication of this research is that neighborhood interventions are not that straightforward, and a health impact assessment of transit investment should be more comprehensive while taking into account individual characteristics and past behavioral factors in determining physical activity benefits of transit projects.

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