Can transit-oriented developments help achieve the recommended weekly level of physical activity?

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ABSTRACT

Modern lifestyles tend to promote sedentary living, putting urban and suburban populations at increased risks for onset of chronic conditions. The promotion of non-leisure physical activity has the potential to provide substantial health benefits. This study aims to describe travel behavior of residents in Transit-oriented developments (TODs) and its impacts on levels of physical activity through utilitarian trips (i.e., routine trips to school, work and grocery shopping). Data is drawn from a survey of residents living in seven geographically-dispersed North American TODs in 2013. Approximately 20% of survey respondents achieved weekly recommended levels of physical activity through their utilitarian trips. Trip frequency was an important factor in achieving recommended weekly physical activity levels; individuals with higher levels of public transport use were more likely to achieved recommended levels of physical activity. Telecommuting might be particularly detrimental to utilitarian physical activity and could reduce public health benefits of TODs, walking friendliness of the residential location had a positive effect on levels of physical activity. Affordability of public transport and good weather contingencies were factors associated with higher in the levels of physical activity. The preference for owning an automobile to do the things that one likes remained a widely held sentiment of survey respondents, decreasing levels of physical activity by 39%. To promote active lifestyles in TODs, governments should invest in infrastructure necessary to facilitate non-car trips especially during bad weather conditions.

Keywords: Physical activity, utilitarian trips, transit, cycling, walking, health, transit-oriented developments

INTRODUCTION

Physical inactivity is growing in North America and active leisure times are decreasing (Transportation Research Board, 2005). Many factors and societal patterns explain this trend including the growth of white-collar jobs, the widespread use of automobiles as a primary mode of travel, and urban sprawl (Brownson & Boehmer, 2004; Ewing, Schmid, Killingsworth, & Raudenbush, 2003). Physical inactivity leads to health problems, straining health care systems and costing tax payers (Janssen, 2012).

In order to overcome this costly social problem, the idea of promoting physical activity (PA), such as walking, through non-leisure activity has flourished in the last couple of decades. Integrating additional walking or cycling time into one's daily routine, such as during commuting, seems, for many, a better public health strategy than creating programs that encourage people to be active during their leisure time. The reason is two-fold. First, walking is the cheapest and the most widely available form of PA (Lee & Buchner, 2008). Second, programs altering people's daily routine have been shown to be less effective in promoting PA than strategies that can be integrated into daily routines (Owen, 1996; Sallis, Bauman, & Pratt, 1998; World Health Organization, 2002). Efforts to augment PA in everyday life have led to the development of various strategies aimed at modifying the built environment to be more conducive to active transportation. To this end, transit-oriented developments (TODs) aim to increase density and walkable destinations around mass transit stations to reduce car-dependence and encourage walking, cycling, and transit usage (Killingsworth, de Nazelle, & Bell, 2003). The contribution of TODs to PA, however, remains relatively unexplored.

This study aims to describe travel behavior of residents in Transit-oriented developments (TODs) and its impacts on levels of physical activity through utilitarian trips (i.e., routine trips to school, work and grocery shopping). Using data from a comparative travel behaviour survey conducted in seven North American TODs and in their vicinities, a log-linear regression model is developed to further define the relationship between PA and travel behaviours.

BACKGROUND

Four types of variables are linked to physical activity in the literature: (1) individual characteristics (genetic and socio-demographics), (2) individual preferences (time allocation and lifestyle preferences), (3) the social environment (social values, norms and preferences in term of PA), and (4) the built environment (Handy, 2005). Our focus in this study is mainly on the effect of built environment characteristics after controlling for the other types of factors mentioned earlier. Figure 1 is a conceptual model summarizing the discussed relations and their link to travel behavior.

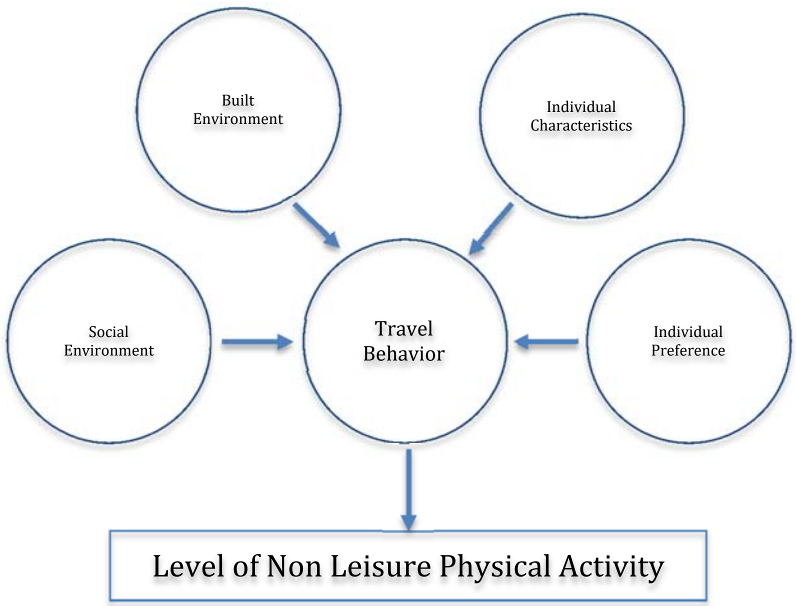


FIGURE 1: Conceptual model

Individuals using public transport or walking for their commute are more likely to meet the recommended daily level of physical activity (RPA) (Besser & Dannenberg, 2005; MacDonald et al., 2010; Morency, Trépanier, & Demers, 2011; Renne, 2005; Stokes, MacDonald, & Ridgeway, 2008; Wasfi, Ross, & El-Geneidy, 2013; Wener & Evans, 2007). This suggests that the built environment and transportation systems are factors that can facilitate or hinder PA and active lifestyles by increasing walking, cycling and transit usage. To illustrate, some studies have shown that residents of more walkable and transit-friendly places report higher levels of physical fitness and lower levels of obesity than residents of more automobile-oriented communities (Frank et al., 2004; Handy, Boarnet, Ewing, & Killingsworth, 2002; MacDonald et al., 2010; Ming Wen & Rissel, 2008; Rundle et al., 2007).

For more than a decade now, urban planners have focused on this idea that land use and design policies can be used to increase public transport use as well as walking and bicycling

(Handy, 1996). The new urbanism movement and the concept of TOD emerged from these efforts. TOD is defined as the area within 10 minutes walking around a public transport station and has the following characteristics: compact, mixed use, and connected to the public transport system through urban design (Renne, 2009). TOD designers aim at creating physical environments more conducive to active transportation (Killingsworth et al., 2003). In fact, TODs are specifically implemented to make walking and cycling more feasible, safe and attractive options, as well as to promote the use of public transport. TOD designers provide nearby walkable destinations like cafés and shops to encourage local walking and cycling trips, as opposed to long-distance car trips (Renne, 2009). Also the presence of TOD near a transit station makes it more easily feasible for residents to use transit to replace some of the daily trips that require car usage due to distances, such as work for example. Although, the use of public transit in TOD is currently under debate (Chatman, 2013), yet there has been several efforts to quantify the impacts of using transit on physical activity.

Three American studies have found that public transport users are more physically active than automobile users (Besser & Dannenberg, 2005; Lachapelle & Frank, 2009; Wener & Evans, 2007). Drawing on the US National Household Travel Survey to assess the relationship between walking and public transport use at the national level, Besser & Dannenberg (2005) found that about one third of public transport users achieve at least 30 minutes of PA per day by walking to and from transit stations. Lachapelle and Frank (2009) found that public transport users were more likely to meet the daily RPA than drivers in their survey research in Atlanta. Wener and Evans (2007) found that the average New York City train commuter walked about 9,500 steps per day, just slightly below the recommended 10,000 steps per day (Tudor-Locke & Bassett, 2004) and 30% more steps than the average car commuter. A recent Canadian study that was able to distinguish trip purpose and type of public transport trip taken showed that approximately 11% of commuters achieved the 30 minutes of RPA just through walking to and from public transport stops when commuting to work or school. In addition, they identified that commuter train users are more likely to achieve public health recommendations than any other transit users (Wasfi et al., 2013).

A key methodological limitation of previous research in this area is the selection bias associated with confounding effects of residential choice, preferences and transportation decisions in cross-sectional designs (e.g., Frank et al., 2004; Lachapelle & Frank, 2009;

Lachapelle & Noland, 2012; Wener & Evans, 2007). Although this paper is also a cross-sectional study (among residents of various TODs), it tries to control for self-selection by evaluating the role of several variables that target why survey respondents moved to their present residence in a public transport friendly environment. Self-selection is a measurement bias that can be captured in a statistical model leading to an over estimation of the impacts of the built environment on travel behavior. For example people who prefer to use transit may be more likely than others to select to live in TOD. By asking the motive of moving to a TOD, we can determine whether a resident walks more in a TOD because they moved to a TOD specifically to walk more or whether the walkability of a TOD has increased their walking. This is one of the approaches that can be used to partially control for self-selection. There has been a breadth of research in the area of self-selection and ways to control for it (Cao, Handy, & Mokhtarian, 2006; Cao, Mokhtarian, & Handy, 2009; Handy, Cao, & Mokhtarian, 2005, 2006). For more details regarding other methods please see Cao et al. (2006).

METHODOLOGY

This study has two objectives: (1) to understand who among TOD residents meets the recommended weekly level of physical activity vis-à-vis their utilitarian trips (school, work, and grocery shopping trips) through the use of descriptive statistics; and (2) to identify which factors among weather, built environment, attitudinal and socio-economic characteristics affect individuals' levels of weekly PA, while controlling for self-selection, using a statistical model.

Data

Study Area, Survey and Sample Size:

Most of the data for our analyses are drawn from a travel behaviour survey conducted on residents in seven different North American TODs in 2013. Five TODs are located in the United States: 1) Rosslyn Station, Arlington, VA; 2) South Orange Station, South Orange, NJ; 3) Berkeley Station, Berkeley, CA; 4) Mockingbird Station, Fort Worth, TX and 5) Downtown Plano Station, Dallas, TX. The two others are Canadian: 1) Equinox Station, Toronto, ON, and 2) Joyce-Collingwood Station, Vancouver, BC. These seven TODs were chosen based on a review of the literature of the most successful TODs in North America. The overwhelming majority of the TOD literature focuses on the United States, with particular developments in New Jersey, California, Texas, Oregon, and Virginia often being recognized for their success (Bae, 2002; Cervero, Murphy, Ferrell, Goguts, & Tsai, 2004; Curtis, Renne, & Bertolini, 2009; Dunphy & Porter, 2006). In Canada, the Joyce-Collingwood and Equinox TODS were selected because they have become internationally renowned (Davison, 2011; Newman, 2005). All TODs in our study are located near to commuter train services.

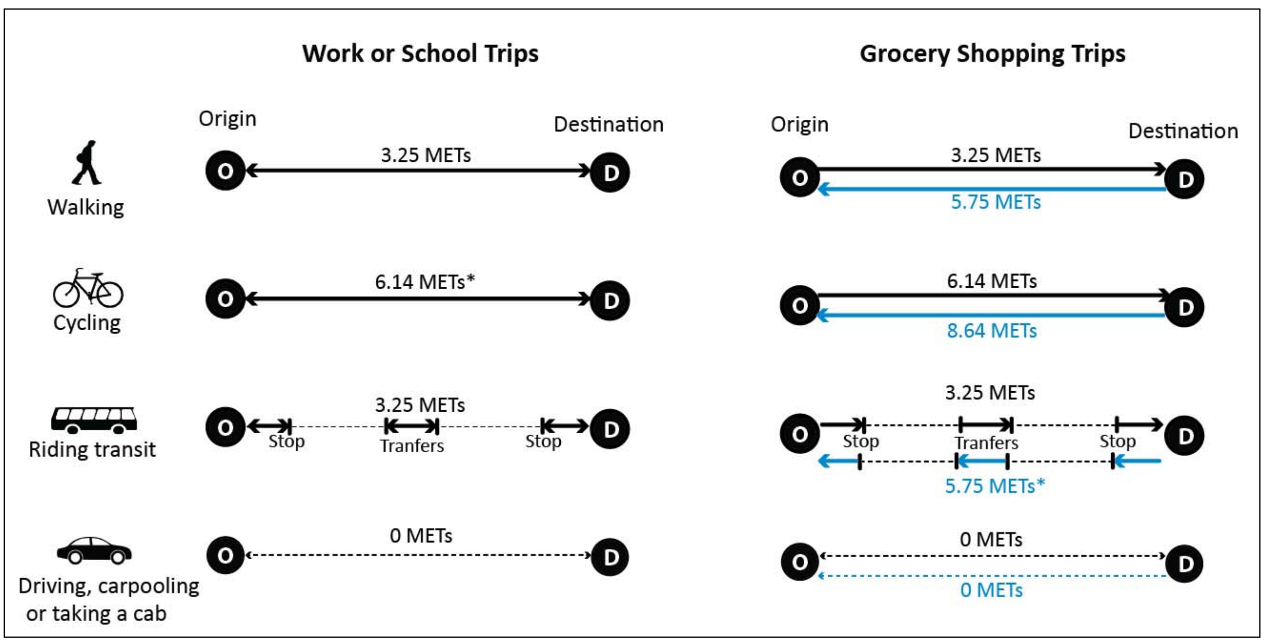
Five thousand addresses within an 800-meter buffer of the transit station were randomly acquired for each American TOD to mail survey requests. The buffer had to be increased to 1,600 meters for each Canadian TOD in order to obtain sufficient numbers of addresses from Canada Post. Due to the difference in buffer length and possible errors in American addresses, readers should keep in mind that respondents are actually “near or in” a TOD. In total, 30,000 survey requests were mailed.

To participate in the survey, participants were directed to the online survey, which included general questions to capture information on the respondents’ previous and current utilitarian and non-utilitarian trip modes, current grocery store and work locations, individual socio-demographic characteristics, as well as previous and current home locations. Children were not included in the study and the average age of the participant was 43 years old. The survey included a series of guided questions to capture detailed information about different aspects of respondents’ trips. The survey was also designed to capture seasonality in travel choices, allowing individuals that switch modes to provide the details of their trip under different weather conditions. Among the 586 received responses, 108 were rejected as incomplete. The final dataset included surveys with mostly completed information from 478 participants.

A conservative estimate of response rates, assuming all survey requests were delivered, was 2% for Rosslyn, 1.4% for South Orange, 3% for Berkeley, 1.5 % for Mockingbird Station, 1.7% for Downtown Plano Station, 1.7% for Toronto, and 2.2% for Vancouver. There were, on average, 83.7 survey responses per TOD. Yet this assumption might not be true and the response might be higher since we received a large number of undeliverable survey invitations due to errors in the purchased listings. These are low response rates. Low response rates, however, do not necessarily correspond to inaccurate data, and other quality indicators like confirmation of previous findings are important (Research, 2010). Moreover, in this study we are primarily interested in exploring factors associated with PA, rather than providing detailed population-level estimates of PA in TODs.

Outcome Variable of Interest: Level of Physical Activity:

To measure the level of PA, the present analysis uses the Metabolic Equivalent of Task (MET) presented in the Compendium of Physical Activity (Ainsworth et al., 2011; Ainsworth et al., 1993; Ainsworth et al., 2000). MET can be define as the ratio of the work metabolic rate to the resting metabolic rate. This measure expresses the intensity and energy expenditure of activities that allows for a comparison among persons of different weights. In other words, MET facilitates comparisons between physical activities. One MET equals one Kcal/kg/hour, which is the equivalent to the energy cost of sitting quietly. Activities are listed in the Compendium as multiples of the resting MET level and they range from 0.9 METs (sleeping) to 23 METs (running at 14 mph). In this study, the use of the MET measure allows the comparison between the average level of PA exhibited by an individual cycling or walking to their destination. However, the Compendium was not developed to determine the precise energy cost of PA within individuals, but instead to provide an activity classification system that standardizes the MET intensities of PAs (Ainsworth et al., 2000).



Notes a) In order to take into account the fact that people carry groceries, 2.5 METs were added to each walking or cycling segment of a grocery-shopping trip on the way back (blue arrows) according to the Compendium. For example, regular walking trips amount to 3.25 METs, but on the way back, when an individual carries groceries, the level of physical activity goes up to 5.75 METs, on average. b) For the access segments of public transport trips, 3.25 MET were attributed to individuals walking to the stops, 6.14 MET to individuals cycling, and 0 MET for those driving to the stop.

FIGURE 2 METs by trip purpose and travel mode choice.

Figure 2 presents how METs were attributed. Respondents were asked to identify their home, work and preferred grocery store on a map and the geographic coordinates were then used to estimate travel times of each respondents for every trip purpose using Google Maps. Their usual departure times and travel modes were also asked for each trip purpose. Only the fastest road option for each trip purpose (in accordance with the travel mode) was kept.

The walking speed used by Google is 4.8 km/h (2.98 mph) and the cycling speed 16 km/h (9.94 mph), which correspond, respectively, to 3.25 METs and 6.14 METs. Around 2.5 METs were added to each return walking or cycling segment of a grocery-shopping trip to take into account the fact that people carry groceries (see blue arrows in Figure 2). Due to unavailability of data, walking time to a respondent's parked car was not considered. The derivation of the weekly MET of each survey respondent (i), is:

$$\text{Weekly MET}_i = F_{qi}\,(M_{si} * t_{i1}) + F_{qi}\,(M_{wi} * t_{i2}) + F_{qi}\,(M_{gi} * t_{i3})$$

Where, M_{si} is the METs associated with the travel mode to school; M_{wi} is the METs associated with the travel mode to work; M_{gi} is the METs associated with the travel mode to the preferred grocery store of the respondent; F_{qi} is the frequency of the trip per week, and t_{ix} the total travel time in hours (walking or cycling) to go and come back from the destination.

Health-enhancing PA for adults aged between 18 and 64 has been defined as an accumulation of 30 minutes or more of moderate- to vigorous-intensity PA on most, preferably all, days of the week (CSEP, 2012; Oja et al., 1998; Pate et al., 1995; USHHS, 2008). Therefore, to meet the recommended level of PA through travel habits and to be considered active, a person must walk at least 30 minutes a day, five times a week, which is equal to a total of 8.125 METs. The 30 minutes can be built up over a day. Ideally, activity should be performed in episodes of at least 10 minutes to achieve the daily recommendation of physical activity (USHHS, 2008).

Key Independent Variables of Interest

Socio-demographics:

The study included five socio-demographic variables: age; sex, access to reduced transit fare, "low income, "University degree", which indicates whether respondents have obtained a university degree or higher; and “Years spent in a TOD”, which indicates the number of years respondents have lived in their current TOD.

Self-selection and Attitudinal Variables:

Self-selection bias is a constant concern in behavioural studies. Do active people consciously decide to move to highly walkable neighbourhoods, or does living in such neighbourhoods make it more likely that people will be active? To control for that bias two variables were used: the “Favour Activity-Friendly Neighbourhoods” variable, which indicated that the individual has chosen his or her current neighbourhood based on its walkability and bikeability, and the “Favour Transit-Proximal Neighbourhoods” variable, which accounts for people that have chosen their current neighbourhood based on proximity to public transport.

To better understand how people’s attitudes and beliefs affect their level of PA, four dummy variables were developed. The “Desire a Car” variable identified respondents for whom owning a car is necessary to feel free and do all the things they like. The “Like to Walk More” variable distinguished individuals who want to walk more frequently than they currently do from those individuals do not feel the need to exercise more. People concerned with the long-term effect of their travel habits on their health are identified by the “Value Health Benefits of Trip Choice” variable. Individuals for whom the environmental impact of their chosen travel mode is important are identified by the “Value Environmental Impacts of Trip Choice” variable.

TABLE 1 Variable used to perform the analysis.

Variables	Description
Socio-demographics	
Age	Continuous
Sex (Female)	1 "Female"; 0 "Male"
Years spent in a TOD	Continuous
Low income (<$40,000)	1 "Annual gross income household < $40,000"; 0 "otherwise"
University degree	1 "University degree"; 0 "otherwise"
Reduced transit fare	1 "Access to a free or reduced transit fare"; 0 "otherwise"
Attitudinal	
Desire a car	1 "I need a car to do many of the things I like to do."; 0 "otherwise"
Like to walk more	1 "I would like to walk more than I currently do."; 0 "otherwise"
Value health benefits of trip choice	1 "Long-term effect of my trips on my health is important."; 0 "otherwise"
Value environmental impacts of trip choice	1 "Environmental impact of my chosen mode is important."; 0"otherwise"
Self-selection	

Favour activity-friendly neighbourhoods	1 "I chose my neighbourhood based on its walkability and bikeability."; 0 "otherwise"
Favour transit-proximal neighbourhoods	1 "I chose my neighbourhood based on its proximity to transit"; 0 "otherwise"
Travel mode used (%)	
Automobile trips	Percentage of weekly trips (includes work, school & grocery shopping) by car
Transit trips	Percentage of weekly trips (includes work, school & grocery shopping) by transit
Walking trips	Percentage of weekly trips (includes work, school & grocery shopping) on foot
Bicycle trips	Percentage of weekly trips (includes work, school & grocery shopping) by bicycle
Frequency	
Number of grocery shopping trips	Discrete: Frequency of grocery shopping trip in a week
Number of work or school trip	Discrete: Frequency of work or school trip in a week
Built environment	
Number of cul-de-sacs	Discrete: Number of dead-ends in a network of 800 meters around the residence
Number of intersections	Discrete: Number of intersections in a network of 800 meters around the residence
Connected node ratio (CNR)	Continuous: Number of street intersections divided by the number of intersections + cul-de-sacs
Walking-friendliness (residence)	Continuous: WalkScore® of the residential location
Walking-friendliness (destination)	Continuous: WalkScore® of the work or school location
Distance to work/school	Continuous: Distance to work or school in kilometers
Other	
Good weather	1 if the observed trip is reported during good weather condition
Meet the weekly RPA	1 "The Individual meets the weekly RPA"; 0 "otherwise"

Travel Mode Choices and Trip Frequencies:

In order to take into account the effect of travel mode choices on the level of individuals' PA, four variables were created: "Automobile trips", "Transit trips", "Walking trips", and "Bicycle trips". These variables are expressed as percentages. They represent the mode share of each individual, during a typical week, for all their utilitarian trips (work, school and grocery shopping trips). The study also takes into account the weekly frequency of trips to work or school

("Number of work or school trip") and to the grocery store ("Number of grocery shopping trip") made by each respondent**.**

Built Environment Variables:

Spatial measures were calculated for each respondent using secondary data sources in a geographic information system. First, the population density by zip code (postal code in Canada) for each respondent was calculated from the data obtained on population and land use from the American and Canadian censuses. Second, the distance (in km) and the travel time from each respondent's residence to his or her work or school were calculated using Google Maps since we possess their geographic coordinates. Third, a measure of street network connectivity, the connected node ratio (CNR) around each individual's residence was developed in ArcGIS to test the hypothesis that greater connectivity allows for more direct travel between destinations and therefore increases the opportunities a person can reach via active modes of transportation. We adapted a previous measure developed by Dill and Tresidder (2005) to modify the CNR such that it is based on the actual network walking distances of each resident rather than Euclidean distance. The number of intersections and dead-ends within an 800-meter (0.5 mile) service area buffer was first determined. Then, the total number of intersections was divided by the number of dead-ends. Values closer to one indicate fewer dead-ends. As aforementioned, our measure is based on actual network walking distances for each resident. Datasets for road networks were easily obtained in most jurisdictions through open sources (OpenStreetMap (2015); New Jersey Geographic Information Network (2014); Alameda County Open Data (2014); Arlington County GIS Data (2014)). However, local street networks do not always equate to the bicycle and pedestrian network, and reliable open source data for bicycle routes and sidewalks are unavailable for each of the seven TODs. Therefore, the connectivity measures used in this study are not able to indicate the level of bicycling or walking suitability.

The Walk Score of each respondent's current residential address was used as a proxy for neighbourhood diversity of opportunities and local accessibility, and was gathered using the online Walk Score tool (Walk Score, 2014). This tool assigns a "Walk Score" between 0 and 100 for each address. Walk Score is a method used for estimating neighbourhood walkability by measuring access to different facilities (Carr, Dunsiger, & Marcus, 2010). This measure has been validated in the past and is known to explain much of the variation in walking behavior in an area (Manaugh & El-Geneidy, 2011). For each address, the tool analyzes hundreds of walking routes to different nearby amenity categories such as retail, recreation, and leisure opportunities. Points are awarded based on the airline distance to amenities in each category. Amenities within a five-minute walk (0.25 miles or 0.4 km) are given maximum points. The tool uses a decay function to attribute points to more distant amenities, where points to attractions that are beyond a 30-minute walk are neglected. Data sources used by this tool include Google, Education.com, Open Street Map, Census and Localeze (Walk Score, 2014).

Choice of Models

To clarify the factors that influence the level of PA achieved through utilitarian trips, this study estimates a statistical model. The dependent variable is the weekly level of physical activity measured in MET, which was found to be not normally distributed. Three tests were performed to reject the normality hypothesis; Shapiro-Wilk test, Pearson's test and Fisher's skewness coefficient test. A natural logarithm transformation was therefore conducted on this dependent variable. All the assumptions of multiple regressions (normality of residual, linearity, homoscedasticity, multicollinearity, etc.) were also tested to ensure the conformity of the models to statistical theory. The use of a hierarchical model to account for the fact that the respondents come from six different cities was also tested. However, this technique did not result in a better fit for the model (Likelihood ratio test $p > 0.05$), in other words we did not notice a significant effect for any TOD specific. Yet, we applied a multilevel technique at the individual level in our analysis to differentiate the levels of physical activity during different weather condition since each individual is present twice in the database.

RESULTS

Descriptive Analysis

Who Meets the Weekly-Recommended Level of Physical Activity (RPA)?

Among the 418 respondents who answered all the questions from the survey, 82 (19.62%) meet the weekly RPA solely by travelling to work or school and to their preferred grocery store. During unpleasant weather conditions this number falls to 72 (17.20%). Survey respondents who were the most physically active and who met the RPA tended to be younger men who were relatively less affluent and had a university degree (Table 2). On average, 32% of those who meet the RPA had access to a reduced public transport fare compared to only 17% for those who do not meet the weekly RPA. This difference is highly significant at the 99% confidence level. This finding is similar to Lachapelle and Frank's results that showed that Atlanta residents with employer-sponsored transit passes were more likely to meet physical activity time recommendations than those who did not have passes (Lachapelle & Frank, 2009). The average number of days in a week that individuals who achieved the weekly RPA by commuting to work or school was also significantly higher (4.6 days) than those who did not meet the RPA (3.3 days), suggesting that telecommuting (i.e., not travelling to work) may negatively influence PA. Individuals who met the weekly RPA also tended to be more aware of the detrimental effect of motor vehicle usage on the environment (60%). However, active and inactive individuals are not statistically differentiated in their concern regarding the long-term effects of their travel mode choice on their health. Those who meet the weekly RPA were also less concerned with the need to have a personal vehicle to do the things they like. Conversely, fewer active individuals were more likely to say that they would like to walk more than they currently do. In addition, respondents that met the weekly RPA were likely to ride transit or cycle more frequently for their utilitarian trips than all other respondents. Finally, the walking-friendliness (Walk Scores) of work or school locations was higher for those who met weekly RPA than for those who did not, while the level of street connectivity (CNR) was not statistically different between these two groups of individuals.

TABLE 2 Description of individuals' attributes using t-test for equality of means.

	Meet the weekly RPA		Do not meet the weekly RPA			
Variables	**Mean**	**SD**	**Mean**	**SD**	**Mean difference**	
Socio-demographics						
Age	39	12	44	15	4.69	**
Gender (Female)	0.38	0.48	0.51	0.50	0.13	*
University degree	0.54	0.50	0.42	0.49	-0.12	**
Low income	0.62	0.48	0.48	0.50	-0.13	**
Reduced transit fare	0.32	0.47	0.17	0.38	-0.15	***
Attitudinal						
Desire for car	0.18	0.38	0.40	0.491	0.21	***
Like to walk more	0.53	0.50	0.72	0.447	0.19	***
Value health benefits of trip choice	0.68	0.46	0.61	0.486	-0.06	n.s.
Value environmental benefits of trip choice	0.63	0.48	0.53	0.500	-0.10	*
Self-selection						
Favour activity-friendly neighbourhoods	0.86	0.34	0.78	0.412	-0.07	n.s.
Travel mode used (%)						
Transit trips (%)	63.74	33.61	18.87	35.32	-44.87	***
Walking trips (%)	20.82	30.72	16.30	33.23	-4.52	n.s
Bicycle trips (%)	8.47	25.48	4.09	17.48	-4.37	**
Automobile trips (%)	7.86	10.90	60.72	44.60	52.86	***
Trip Frequency						
Number grocery shopping trips	1.86	1.42	1.70	1.10	-0.16	n.s.
Number of work or school trips	4.69	1.20	3.36	2.16	-1.33	***
Built environment						
Walking-friendliness (destination)	75.11	24.57	55.71	36.83	-19.39	***
Walking-friendliness (residence)	74,31	15.29	73,52	17.10	-0.78	n.s.
Connected Node Ratio (CNR)	0.92	0.01	0.91	0.01	-0.01	n.s.

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

What is the effect of weather conditions on levels of physical activity (PA)?

On average, the level of PA of each respondent decreased by 0.57 METs per week during unpleasant weather conditions (Table 3). Conditions considered unpleasant varied for individuals and geographic locations. For instance, respondents located in Canada or in northern American TODs were mainly concerned by ice and snow on the ground. Regarding bad weather, 54.5% of the respondents checked “heavy rain” as unpleasant weather, 37.8 % the presence of “ice on the ground", 30.1 % the presence of " snow on the ground", 16.5% "heavy wind", and 11.7% "light rain". Temperature was also a factor to consider. Respondents reported that that too hot (24.4%) or too cold (22.2%) temperatures may alter their travel mode choice or modify their trip schedule. During bad weather, the average weekly proportion of trips by foot and by bicycle diminished by 4.4% and 2.8% respectively, while the proportion of trips by automobile (either as driver or passenger) increased by 6.3%, on average.

TABLE 3 Description of individuals' level of PA and travel mode by weather conditions.

	Pleasant weather		**Unpleasant weather**			
	Mean	**SD**	**Mean**	**SD**	**Mean difference**	
Weekly level of PA (METs)	4.29	6.23	3.70	6.55	0.58	***
Transit trips (%)	27.67	39.24	28.45	39.52	-0.78	n.s.
Walking trips (%)	17.18	32.77	12.82	28.08	4.36	***
Bicycle trips (%)	4.95	19.36	2.14	13.21	2.81	***
Automobile trips (%)	50.35	45.41	56.61	44.64	-6.25	***

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Statistical Model: Which Factors Influence the Level of PA?

A log-linear model was developed to understand which factors influence the weekly level of PA for TOD residents (**Error! Reference source not found.**). The model includes built environment and weather condition variables. It was impossible to have the built environment and weather variables with travel mode choice variables in the same model since individual travel mode choice can be affected directly and indirectly by the built environment characteristics and weather in some cases. Also because the levels of MET developed depends on the mode used. Accordingly, mode choice variables were excluded from the model.

The final model presented only displays the ''Walking-friendliness'' variables, as built environment variables, since they have more explanatory power than CNR and density measures. While having positive associated with PA, population density (km^2) and CNR are too highly correlated with the two Walking-friendliness variables, as measured by the Walk Score®, to be incorporated in the same model ($r > 0.3$ in both cases). Number of years spent in a TOD, distance to work or school, "Low income" "Age", "University degree", "Health", and "Environment" were not meaningfully associated with PA and excluded from the final models in the interests of parsimony and interpretability. The output from the log-linear regression model is reported in table 4 using the natural log of MET as the dependent variable.

TABLE 4 Log-linear regression models of physical activity as measured by MET

Variables	MET Regressions
Favour activity-oriented neighbourhoods (yes)	0.27**
	(0.04-0.49)
Desire a car (yes)	-0.39***
	(-0.58--0.21)
Like to walk more (yes)	-0.29***
	(-0.49--0.10)
Female (yes)	-0.12
	(-0.29-0.05)
Reduced transit fare (yes)	0.44***
	(0.21-0.67)
Walking-friendliness (residence)	0.009***
	(0.004-0.01)
Walking-friendliness (destination)	0.008***
	(0.006-0.01)
Good Weather (yes)	0.14***
	(0.07-020)
Constant	-0.22
	(-0.71-0.26)
Sd(cons)	0.81
SD(Residual)	0.47
Log likelihood	-895.98
AIC	1813.97
BIC	1865.19
Observations	778
Groups	379

95% confidence intervals in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Favouring to live in an activity-friendly neighbourhoods was associated with a 27% increase in the level of PA. Reporting a desire for a car to do many things one like was associated with a 39% reduction in physical activity. On the other hand, respondents who answered that they would like to walk more than they currently do had METs that were 29% lower than other individuals indicating that these individuals are less active.

Women were associated with lower levels of physical activity compared to men (12%), although the variable was not statistically significant we preferred to keep it in the model due to the value associated to this difference as it requires further studies in the future (the difference was statistically significant in table 2). The model also shows that people with access to a reduced or free transit fare were associated with 44% increase in their levels of physical activity compared to those who do not.

The walking-friendliness of the residence location and of the work or school location, as measured by the Walk Score®, are importantly related to PA. A ten point increase in Walk Score® at home and work (which ranges from 0-100) was associated with increases in the level of PA by 9% and 8%, respectively. Finally, good weather conditions was associated with 14% increase in MET compared to un-pleasant weather, as individuals tend to use active transport modes more during good weather condition. Several variables were tested and dropped from the model as they did not show statistical significance. For example, favouring living in transit-proximal neighbourhoods, distance to work/school, and distance to the preferred grocery store (see other tested variables in table 2).

DISCUSSION AND CONCLUSION

The goal of this study was to better understand who meet the weekly recommended level of physical activity and why. In other words, to explore which factors are more closely associated with TOD residents' level of PA, not to provide population-level estimates of PA. We found that aproximately 20% of TOD residents achieved the weekly recommended levels of physical activity solely by travelling to work or school and to their preferred grocery store. This compares very favourably with physical activity levels of the general population of North America. In Canada, only 5% of individuals achieve weekly recommended levels (Colley et al., 2011), suggesting that living in a TODs do promote PA.

We found that adverse weather conditions were detrimental to utilitarian PA, survey respondents tended to switch to car usage during unpleasant weather. It is important to note that most respondents analysed in this study can be considered "choice riders", since each household had access to at least one personal vehicle and the switching to car usage during bad weather condition indicate the presence of an alternative to these individuals. Transit agencies should promote and advertise transit usage as a viable alternative during days of unpleasant weather, especially in places where ice and snow are the reason why people opt for their automobiles as alternative. Efficient sidewalk snow removal policies around stations can complement transit agencies' efforts to better promote their services. Better shelters, more convenient facilities around stops, and air-conditioned vehicles can also potentially encourage people to use transit during very rainy, cold or hot days. According to the results of this study, individuals with reduced transit fare are more likely to meet the RPA. Therefore, transit agencies should also consider the implementation of reduced or free transit fare programs for the segment of their customers more at risk of switching to car usage during unpleasant weather conditions.

The built environment variables tested in this study suggest that the more walkable an environment is, the more likely people living in it will use active travel modes. In order to limit the negative effects of physical inactivity and foster active lifestyles, strategies aimed at limiting distance between residents and opportunities (e.g., work locations, groceries stores, service providers and entertainment) or transforming the built environment to make it more conducive to active modes of transportation needs to be further explored. Therefore our findings establish that environments designed to encourage active modes of transportation, such as TODs, seem to be promising.

Social changes in the employment market, educational system and in shopping behaviours influence the level of PA. Regular employment is no longer confined to one work place, especially for professionals, managers and other white-collar workers (Felstead, Jewson, & Walters, 2005a, 2005b). Telecommuting and telework are increasing. In addition, online degrees, which are earned at almost no cost compared to regular in-class courses, are becoming more popular as shown by online enrolment records (Allen & Seaman, 2013). Our findings of the importance of trip frequency on the level PA suggest that the rise in popularity of remote working and schooling may increase physical inactivity in the population if the level of PA performed during a commute is not replaced. To counterbalance these social changes, transit services could be branded as places where commuting time can be productive and useful rather than lost. Furthermore, the expansion of grocery delivery and teleshopping has an impact on behaviours related to grocery shopping trips and commercial development.

Many respondents that are less active in this study perceive that to engage in the types of activities they like, they need to own a car. With the increased popularity of car sharing programs, it is now easier for those who do not own personal vehicles to reach destinations and opportunities inside and outside the transit network perimeter of a region. Car sharing programs are like transit stations, people need to walk to them, which encourage PA. Cities should consider and encourage the development of such program in their jurisdiction. In addition, to change the public calculus regarding the need of owning an automobile, public transport investments will need to be aggressive, enhancing networks to allow greater and more flexible access to more destinations in various parts of a region and not just central locations. Better, more frequent, and reliable transit links between work destinations and residential locations across urbanized areas and outside traditional peak hours is essential to serve entire populations (Anderson, Owen, & Levinson, 2012; Kim & Kwan, 2003; Legrain, Buliung, & El-Geneidy, 2015). These improvement strategies have the potential to increase transit usage, and as this study shows individual with greater transit usage are more likely to meet the weekly RPA.

One should bear in mind that the level of PA calculated in this study was based on self-reported information from a small sample to their most usual destinations. To ensure the accuracy of the data and to validate our results, future work should track trips and steps of TOD residents more closely over a specified time period through pedometers or mobile apps. We found recruitment to our survey of TOD residents rather challenging and future projects should aim to reach more residents through non-traditional methods of recruitment. Also, due to sample size limitation, this study does not differentiate between the effects of various transit modes (Bus, subway, train, etc.).

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