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Impact of travel mode shift and trip distance on active and non-active transportation in the São Paulo Metropolitan Area in Brazil

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ABSTRACT

Background. Changes in urban mobility play a major role in transforming metropolitan areas into healthier places. This study quantified the impact of changes in travel mode shift and trip distance on active and non-active transportation of working age adult population of São Paulo.

Methods and findings. Through different scenarios, we estimated the daily time spent in transportation per inhabitant (divided in active and non-active transportation time) and the proportion of inhabitants accumulating 30 min or more of daily active transportation. The replacement of individual for collective motorized modes in long distance trips (>1000 m) in combination with the substitution of long for short trips positively impacted all outcomes. Compared to the current situation, there was an increase in the active transportation time (from 19.4 to 26.7 min/inhabitant), which also increased the proportion of adults active for transportation (from 27.6% to 35.4%). Additionally, the non-active transportation time decreased (from 67.0 to 26.2 min/inhabitant), which helped to reduce the total time spent in transportation (from 86.4 to 52.9 min/inhabitant).

Conclusion. Transport and urban planning policies to reduce individual motorized trips and the number of long trips might produce important health benefits, both by increasing population levels of active transportation and reducing the non-active and the total time of daily trips.

Introduction

Between the 1950s and 1990s, Latin America faced a rapid and chaotic process of urbanization. This leads to a current urbanization rate of almost 80% and the creation of large metropolitan areas, also known as megacities, such as Mexico City and São Paulo (UN-HABITAT, 2012). Urban mobility in these cities became reliant on individual motor vehicles, which leads to environmental degradation of the natural and built environment and deterioration of public transport systems (Vasconcellos, 2001; WHO, 2011). This process increased social inequalities and created many health impacts still to be resolved (UN-HABITAT, 2012). Poor urbanization also reduces the access and opportunities for employment, education, protection from environmental risks, public service use, and other determinants of well-being (Commission on Social Determinants of Health, 2008). Thus, urban mobility improvements are needed to improve urban life and to tackle the burden of non-communicable diseases (Rydin et al., 2012; WHO, 2011).

Urban mobility, which is influenced by transport and land use planning, plays a direct role on health through daily travel time and travel modes (Hoehner et al., 2012; Stone et al., 2014). Poor urban mobility, such as that of the São Paulo Metropolitan Area, leads to longer trips in daily transportation, two thirds of which are non-active forms and involve either sitting or standing in private or public transportation vehicles (Companhia do Metropolitano de São Paulo, 2008). In this sense, transport and urban planning are closely related to physical activity, free time and sedentary behavior.

Although changes in urban mobility present great potential for increasing population levels of physical activity (Hoehner et al., 2012; Pratt et al., 2012), health-oriented modifications might be challenging. For instance, while increasing walking trips is a health-promoting strategy, long trip distances pose a significant barrier to achieve this goal (Hoehner et al., 2012). While distance is less of a problem for cycling in comparison to walking, there are several barriers of the urban environment in the context of Latin American cities (Mosquera et al., 2012), including high risks of traffic accidents and injuries (Garcia et al., 2013). Therefore cycling might still not be a feasible option for a significant proportion of people, particularly for women (Mosquera et al., 2012).

From the health effect point of view non-active transportation can be seen as a lost opportunity for physical activity and it can also impact health through sedentary behavior. Non-active transportation can be seen as a proxy of sedentary behavior, an independent risk factor for

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obesity and abdominal obesity (Mummery et al., 2005). Longer commuting times, commonly found in large cities, have been associated with lower cardiorespiratory fitness and higher metabolic risk (Hoehner et al., 2012). Also, people who spend a large amount of time sitting in traffic have been found to display a lower sense of community and higher social isolation (Hart and Parkhurst, 2011). This is particularly problematic for Sao Paulo, where people spend an average of 1.6 h per day in traffic (Rede Nossa Sao Paulo, 2013). Changes in transport and urban planning have to take into account this complex context in order to achieve a better balance that favors active transport and minimizes both non-active and total daily travel time, while considering the urban environment of large Latin American cities. Modeling these changes allows us to create alternative hypothetical scenarios that can help to determine the best-case alternative for the promotion of active travel and reduction of trip distance. Although not originally designed for health purposes, household travel surveys are a reliable but underused source of information that can provide input for time replacements in the transport context. Some studies have used travel surveys to study transportation and health outcomes (Maizlish et al., 2013; Rissel et al., 2012; Rojas-Rueda et al., 2012; Woodcock et al., 2009, 2013). To address this knowledge gap, we explored the impact of travel mode changes and trip distance on total travel, active transportation, and non-active transport time in working age adult population living in the São Paulo metropolitan area. For this aim we modeled three scenarios using information from the São Paulo Metropolitan Area Household Travel Survey.

Methods

Data source

The main data source of this study is the São Paulo Metropolitan Area Household Travel Survey (HTS), an on-going household travel survey carried out by the transportation sector every ten years. The 2007 HTS was conducted from August 2007 through April 2008 comprising the 39 cities of the São Paulo Metropolitan Area (hereafter, São Paulo), the largest metropolitan area of South America (19,161,048 and 20,128,227 inhabitants in 2007 and 2013, respectively) (SEADE Foundation, 2014).

The sampling plan of the HTS followed a complex and stratified design to produce estimates representative of the São Paulo population. The sampling strategy was based on the roll of electricity consumers of the city electricity companies, which covers more than 98.4% of the area's population (IBGE, 2011). To select the households, the São Paulo territory was divided into 460 traffic analysis zones, which were contiguous and compatible to the administrative boundaries of the metropolitan area, its cities and districts. The criteria to define the zones also took into account the trip generation and attraction, the transport and road structure, land use characteristics, and the existence of physical barriers and open areas. Each zone was used to randomly select the primary study unit (household) according to three levels of electricity consumption — a proxy for number of individuals in the household and income. For both years, each zone had its sample size calculation, with a total sample size target for São Paulo of 30,000 households.

In order to accomplish this sample size target, 54,571 households were visited (26.4% were either not a family residence, closed or empty household; 17.5% refused to participate; and 1.1% did not have information from all residents). In case of not valid household, another household from the same zone and level of energy consumption was randomly selected. HTS data was weighted to adjust for the selection probabilities at the individual level and to make the sample representative for the study area. The full HTS provides a comprehensive source of data for 29,957 households, 91,405 people, and 169,665 trips.

Data from HTS were obtained and recorded in a standardized manner for every household member through face-to-face interview on a weekday. Household-level data included number of families and residential location. Family information included number of members in the household, residence ownership, and number of house goods, including bicycles and vehicles. Individual-level data included age, gender, education, employment status, income, and place of work and study. Trip-level data is related to one-way trips undertaken on the day before the interview and includes origin and destination, travel mode, number of times one shifted the mode of transport, mode shift places, purpose, distance, and time of departure and arrival.

We used only information for working age adult population (age ≥18 y and ≤59 y), from a sample of 56,428 people. Out of the 116,947 trips performed by these people, 989 trips were removed due to lack of information about distance, with a remaining sample of 56,261 people and 115,958 trips. Data analysis was conducted in 2013. Approval to conduct the research was obtained from the School of Public Health Ethics Committee (University of São Paulo).

Trip characteristics definitions

Trip duration was calculated from the difference between the arrival time at destination and the departure time at the origin. We calculated trip distance on the Google Maps street-network database using the trip origin and destination geographic coordinates. We considered short trips those with a distance shorter than or equal to 1000 m (≤1000 m). Mode of travel was defined as the type of transport used in each trip or trip segment. Active transportation modes were walking and cycling; individual motorized modes were car, motorcycle, and taxi; and collective motorized modes were subways, trains and buses. Purpose was determined based on the purpose of the trip's destination. If the destination was returning home, then purpose was based on the trip's origin. We considered three trip purposes: work, school, and others (shopping, health, leisure, looking for job, and personal errands).

Outcomes

Daily time spent in active transportation per inhabitant: sum of all individuals' hours spent walking or cycling in every trip (could be zero or the entire trip) divided by the total number of individuals in the population, including those who did not travel on the day before the interview.

Daily time spent in non-active transportation per inhabitant: sum of all individuals' time spent in motorized trips or trip segments divided by the population, including those who did not travel on the day before the interview.

Daily time spent in transportation per inhabitant: sum of the two previous indicators, i.e., the sum of the time spent in transportation divided by the entire population.

Proportion of working age adults active in transportation: proportion of individuals that accumulated 30 min or more of walking/cycling regardless of trip segment duration.

Creating the scenarios

Using the routine data from the HTS, we developed three scenarios for São Paulo and compared them to the real situation in 2007. The algorithms used for this calculation were the following:

Where t is an individual's trip time and T is the accumulated person time,

$$T_{\text{total/inhabitant}} = \Sigma(T_{\text{active}} + T_{\text{non-active}})/N_{\text{inhabitants}}$$

where

$$T_{\text{total}} = T_{\text{active}} + T_{\text{non-active}}$$

$$T_{\text{active}} = \Sigma(t_{\text{active}});\ t_{\text{active}} = t_{\text{walking}} + t_{\text{bicycling}}$$

$$T_{\text{non-active}} = \Sigma(t_{\text{non-active}});\ t_{\text{non-active}} = t_{\text{individual motorized mode}} + t_{\text{collective motorized mode}}.$$

In the first scenario (scenario 1), the impact of the substitution of any motorized mode of travel by walking on short trips (≤1000 m) was explored. For that, we recalculated the trip duration by multiplying its distance with the average walking speed of 13.3 min/km (approximately 4.5 km/h) (Ainsworth et al., 2011). Walking was the chosen active mode for substitution in all scenarios because it is a more feasible mode of transport for all populations when compared to cycling, and has an average speed that is less dependent on environmental conditions, such as slope.

Scenario 2, in combination with scenario 1, explored what would be the impact of the substitution of an individual motorized mode of travel by a collective motorized mode on long trips (>1000 m). For that, we assumed that individuals would accumulate the mean time of active transportation associated with long-distance collective motorized trips per each individual motorized trip replaced. Also, we calculated the new total trip duration by adding the mean difference in total duration of collective motorized trips compared to individual motorized trips according to deciles of trip distance, since the mean difference in total trip duration between individual and collective motorized trips increases with longer traveled distance.

Finally, scenario 3, in addition to scenarios 1 and 2, focused on the impact of the substitution of 50% of long trips by short trips, as could be done in a more compact city where origins and destinations were closer to each other. For that, we considered that individuals would have an increase of 0.97 min in active transportation per each long trip replaced, since this is the difference between the mean active transportation time accumulated in long and short trips. To calculate the new mean total duration, we added, for each trip replaced, the difference in mean total duration between collective motorized long-distance trips and walking short-distance trips. We have to note that, on scenario 3, after all the substitutions, no trip is now made using an individual motorized mode, whether they are short or long-distance trips. Thus, scenario 3 should be viewed as best case or maximum impact scenario which requires large changes in the location of residential and work places inside the city.

In our study, we assumed that everything else on São Paulo mobility patterns would remain stable except for what had been modified in the scenarios. We also assumed no synergy among the proposed changes.

Statistical analysis

Analyses were performed to describe the distributions of participants' sex, age, and education and the presence of cars, motorcycles and bicycles at home, with their corresponding 95% confidence intervals (95% CIs). Descriptive analysis of the trips was also performed, identifying the frequency and distribution of trips according to trip characteristics (mode, purpose and distance), as well as median duration of the complete trips and median duration of the active segment (segment done by walking or cycling) of the trips with their respective interquartile range (p25–p75). Data analyses were carried out using the STATA statistical package, version 12.0 (StataCorp, College Station, TX, USA), considering the survey's weighting factors.

Results

Population and trips characteristics

The working age adult population São Paulo in 2007 was mostly female (53.0%). More than half of the sample completed at least high school level education (56.0%) (Table 1). Of that population, 72.3% of adults reported traveling on the reference day. The median number of trips performed per adult per day was 2 (interquartile range: 0–2), same as for the number of motorized trips (2; 0–2). The median number of trips with at least 10 min of walking per adult per day was 0 (0–1). The median distance accumulated in all trips per adult per day was 9.9 km (0–32.5).

Table 1
Sociodemographic distribution estimates[a] of the adult population in the São Paulo Metropolitan Area (SPMA). Household Travel Survey (n = 56261), August to November 2007 and February to April 2008.

Sociodemographic characteristics	SPMA 2007		
	%	CI (95%)	
Sex			
Male	47.0	46.6	47.4
Female	53.0	52.5	53.5
Age (years)			
18–24	19.5	19.0	20.1
25–34	27.0	26.2	27.7
35–44	23.2	22.5	23.8
45–54	21.7	21.1	22.3
55–59	8.6	8.1	9.1
School grade			
No schooling or incomplete elementary schooling	8.8	7.7	9.8
Elementary schooling/	16.8	15.9	17.6
Middle schooling	18.5	17.8	19.2
High schooling	42.4	41.3	43.5
Graduate schooling	13.6	12.2	14.9
Car at home			
None	44.7	42.9	46.5
One	40.5	39.2	41.8
Two or more	14.8	13.5	16.1
Motorcycle at home			
None	90.4	89.6	91.2
One	9.0	8.2	9.7
Two or more	0.6	0.5	0.8
Bicycle at home			
None	62.0	60.7	63.3
One	27.0	25.9	28.1
Two or more	11.0	10.2	11.8

[a] Estimates based on sampling weighting factors.

Table 2 describes the characteristics and duration of trips. Moreover, short-distance trips were mainly accomplished by walking (83.4%) or in individual motorized modes (14.0%), while long-distance trips were mainly completed in collective and individual motorized modes (47.8% and 38.9%, respectively). Cycling accounted for 1% of trips in both short and long-distance trips. Only 12.5% of trips to work and 31.5% of trips to school were short.

Impacts on daily time spent in transportation per inhabitant

In scenario 1, we quantified the impact of the substitution of any motorized mode by walking in short trips. This replacement had small impact on active, non-active, and total daily time spent in transportation per inhabitant (Table 3). Therefore, the proportion of adults engaging in active transportation remained stable compared to the real situation (increased 0.2 percentage points — pp).

In scenario 2, the additional replacement of individual by collective motorized modes in long trips largely increased the daily time of active transportation per inhabitant (6.7 min or 34.2% increase), which positively influenced the proportion of adults active through transportation (7.4 pp or 26.6% increase). However, this scenario also increased daily total and non-active transportation time per inhabitant (14.3 min or 16.6% increase and 7.6 min or 11.4% increase, respectively) (Table 3).

Finally, in scenario 3, the combination of the two previous scenarios along with the substitution of 50% of long by short trips positively impacted all outcomes. The increase on the daily time of active transportation per inhabitant did not change from scenario 2 to scenario 3, which helped to maintain the level of active adults during transportation. Nevertheless, daily time of non-active transportation per inhabitant dropped substantially (−47.8 min or 64.6% decrease), consequently

Table 2
Characteristics[a] and duration of trips performed by adults in the SPMA according to trip mode, purpose and distance. Household Travel Survey (n = 115,958), August to November 2007 and February to April 2008.

Trip characteristics	Trips (n)	%	Total median duration (minutes)	p25–p75	Median duration of the trip's active stretch[d] (minutes)	p25–p75
Mode						
Predominantly collective motorized [b]	38,733	40.2	60	40–95	10	7–17
Predominantly individual motorized [c]	48,900	34.5	25	15–40	2	0–2
Exclusively cycling	1,089	1.0	20	15–30	20	15–30
Exclusively walking	27,236	24.3	15	10–20	15	10–20
Purpose						
Work	66,412	60.1	40	20–75	7	2–15
School	22,227	19.3	20	10–40	10	2–15
Others	27,319	20.6	30	15–50	5	2–15
Distance						
≤1000 m	96,217	16.8	10	5–15	5	10–15
>1000 m	19,741	83.2	40	20–70	7	2–15
Total	115,958	100.0	30	15–60	7	2–15

[a] Estimates based on sampling weighting factors.
[b] Includes trips in which the larger stretch was performed by the following modes: bus, microbus, school bus, metro or train.
[c] Includes trips in which the larger stretch was performed by the following modes: car (driver or passenger), motorbike and taxi.
[d] Part of the trip performed by walking or bicycling.

reducing the total daily time of transportation per inhabitant (−47.4 min or 47.3% decrease) (Table 3).

Discussion

Using a representative sample of the largest metropolitan area in Brazil and testing various transportation scenarios, we found that only a combination of shorter trip distances, more walking and less car based transportation, could most influence population health by concomitantly reducing the total and the non-active daily commuting time and increasing active daily commuting time. This increase in active transportation could lead to a higher proportion of the population achieving the recommended levels of physical activity through transportation. These results, consistent with those of similar studies from large urban cities in Europe and North America (Maizlish et al., 2013; Rissel et al., 2012; Rojas-Rueda et al., 2012; Woodcock et al., 2009, 2013), highlight the importance of exploring this topic also in the Latin America region, which has particular urban and social characteristics.

The total proportion of short trips (≤1000 m) was 25%, most of which are already made by active forms of transportation, mainly walking. According to the results from our scenario 1, the impact of a shift from motorized modes to walking in short trips on the mean proportion of active travel is still low, despite the fact that the adult effectively making the shift would add around 13 min of walking for each kilometer replaced. A potential solution to promote active transportation is to increase the number of trips that are done by collective public transport versus individual private means, as shown in scenario 2. In addition, non-active transportation time could be effectively reduced, according to scenario 3 by increasing the number of short trips within the city. This could also reduce sedentary time of the population by reducing the time spent sitting in car and public transport. Thus, improvements in the public transportation system and in urban planning in São Paulo are imperative (Haines et al., 2009; Hartog et al., 2011; Maizlish et al., 2013; Woodcock et al., 2013).

To our knowledge, this study is the first to model transport scenarios in order to evaluate the health determinants of changes in urban mobility in a Brazilian setting. Additionally, unlike most of the modeling studies, it aimed to estimate impacts not only in physical activity but also in sedentary behavior, by using non-active transport as a proxy. Both are important and independent health issues and risk factors for obesity and other non-communicable diseases (Dunstan et al., 2012; Hoehner et al., 2012; Owen et al., 2010; Proper et al., 2007; Sugiyama et al., 2012; Thorp et al., 2010). Given the growing evidence on the impact of sedentary behavior on health outcomes, particularly on obesity and cardiovascular health (Hoehner et al., 2012; Mummery et al., 2005), our findings underscore the importance of not just increasing active transportation, but also reducing sitting time on daily commuting.

Transportation and urban planning sectors should be increasingly involved with public health in order to create coordinated and synergistic strategies for promoting active commuting and reducing sedentary behavior (Pratt et al., 2012). Another important implication from our

Table 3
Indicators of transportation in the real situation and in the three alternative scenarios for the adult population of the SPMA. Household Travel Survey, August to November 2007 and February to April 2008.

	Active through transportation[a]	Daily time of transportation/inhabitant	Daily time of active transportation/inhabitant	Daily time of non-active transportation/inhabitant
	% (CI 95%)	Minutes (CI 95%)	Minutes (CI 95%)	Minutes (CI 95%)
Real situation	27.6 (26.5 to 28.6)	86.4 (83.9 to 89.1)	19.4 (18.8 to 20.0)	67.0 (64.5 to 69.5)
Scenario 1 (Substitution of short-distance[b] individual motorized trips by walking)	27.8 (26.8 to 28.9)	86.2 (83.5 to 88.9)	19.6 (19.0 to 20.3)	66.4 (63.9 to 98.9)
Scenario 2 (Scenario 1 + Substitution of long-distance[b] individual motorized trips by collective motorized trips)	35.2 (34.1 to 36.4)	100.4 (97.7 to 103.1)	26.3 (25.6 to 27.0)	74.0 (71.4 to 76.5)
Scenario 3 (Scenarios 1 and 2 + Substitution of 50% of long trips by short trips)	35.4 (34.2 to 36.5)	52.9 (50.7 to 55.2)	26.7 (26.0 to 27.4)	26.2 (23.9 to 28.5)

[a] Adults aged 18 to 59 years old which accumulated 30 min or more in walking or bicycling trips.
[b] Short trips: ≤1000 m; Long trips: >1000 m.

study, as exemplified by scenario 3, is the fact that shorter trip distances and higher density and diversity compared to the status quo can increase the number of people meeting physical activity recommendations through transportation by a mean of 7 min in daily time of active transportation at the population level. Several land-use planning and community design alternatives such as Smart Growth and livable communities have emerged in recent years. Such movements call for a more integrated design of neighborhoods, with less fragmentation between residential and work places, thus facilitating active transportation, while making it safe and enjoyable (Degaspari, 2013; Fenton, 2005; Jerrett et al., 2013; Sykes and Robinson, 2014).

This study has some limitations. The 2007 HTS has the common limitations of self-reported data, in this case tending to overestimate trip duration (Kelly et al., 2013). Also, trips shorter than 500 m whose purpose was not work or school were not reported, which could have underestimated the time of active transportation at baseline. Nevertheless, considering the short distance and the low proportion of trips for other purposes, the impact is likely small. We used a much less sophisticated modeling approach, which was unable to consider synergies among changes. Concerning distance calculation, another limitation is related to some inaccuracy in Google Maps in Brazil, especially in lower income areas (Davis Junior and de Alencar, 2011).

Notably, the finding that people spend a large amount of time traveling to work or school highlights the need for and supports the concept of a compact city where both walking and bicycling are more easily attainable. Unfortunately, economic drivers of megacities, such as housing and rentals prices, have historically forced people to live further away from their destinations and into the periphery of the urban area (WHO, 2011), thus increasing commuting times and reducing opportunities to fully experience the city (Rydin et al., 2012; WHO, 2011). Nevertheless, the benefits of active commuting not only for individual and population health but also for environmental reasons (Maizlish et al., 2013; Woodcock et al., 2009) should be recognized by policy makers at local and global level, who should continue to implement policies, incentives and regulations that discourage private vehicle use (De Nazelle et al., 2011; Dora and Racioppi, 2003).

In fact, some plans have already been developed worldwide in favor of a more egalitarian, accessible and car-independent urban mobility system — similar to some of our scenarios. This includes São Paulo's plan to become a city in which every destination could be reached in not more than 30 min (Prefeitura de São Paulo, 2012) as well as recent changes in its Master Plan in 2014 (Prefeitura de São Paulo, 2014), including the development of its Urban Mobility Policy (Prefeitura de São Paulo, 2014). The conditions under which these changes are most likely to occur are uncertain, but it seems to be a combination of a social mobilization around the fight for political collective rights together with sustained pressure from the environment on society (Harvey et al., 2013; Köhler et al., 2009).

Conflict of interest statement

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