Journal of Transport & Health 14 (2019) 100604

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Beyond the bus stop: Where transit users walk

Jerzy Eisenberg-Guyot[a,*], Anne V. Moudon[b], Philip M. Hurvitz[b], Stephen J. Mooney[a,c], Kathryn B. Whitlock[d], Brian E. Saelens[d,e]

[a] Department of Epidemiology, University of Washington School of Public Health, Seattle, WA, USA
[b] Urban Form Lab and Department of Urban Design and Planning, University of Washington College of Built Environments, Seattle, WA, USA
[c] Harborview Injury Prevention & Research Center, University of Washington, Seattle, WA, USA
[d] Seattle Children's Research Institute, Seattle, WA, USA
[e] Department of Pediatrics, University of Washington School of Medicine, Seattle, WA, USA

ABSTRACT

Objectives: Extending the health benefits of public-transit investment requires understanding how transit use affects pedestrian activity, including pedestrian activity not directly temporally or spatially related to transit use. In this study, we identified where transit users walked on transit days compared with non-transit days within and beyond 400 m and 800 m buffers surrounding their home and work addresses.
Methods: We used data collected from 2008 to 2013 in King County, Washington, from 221 non-physically-disabled adult transit users, who were equipped with an accelerometer, global positioning system (GPS), and travel diary. We assigned walking activity to the following buffer locations: less than and at least 400 m or 800 m from home, work, or home/work (the home *and* work buffers comprised the latter buffer). We used Poisson generalized estimating equations to estimate differences in minutes per day of total walking and minutes per day of non-transit-related walking on transit days compared with non-transit days in each location.
Results: We found that durations of total walking and non-transit-related walking were greater on transit days than on non-transit days in all locations studied. When considering the home neighborhood in isolation, most of the greater duration of walking occurred beyond the home neighborhood at both 400 m and 800 m; results were similar when considering the work neighborhood in isolation. When considering the neighborhoods jointly (i.e., by using the home/work buffer), at 400 m, most of the greater duration of walking occurred beyond the home/work neighborhood. However, at 800 m, most of the greater duration of walking occurred within the home/work neighborhood.
Conclusions: Transit days were associated with greater durations of total walking and non-transit related walking within *and* beyond the home and work neighborhoods. Accordingly, research, design, and policy strategies focused on transit use and pedestrian activity should consider locations outside the home and work neighborhoods, in addition to locations within them.

1. Introduction

Public-transit investment can improve public health. Recent research has connected transit use to more physical activity temporally linked to transit use (Brown et al., 2015; Miller et al., 2015; Saelens et al., 2014), improved access to services and employment for marginalized groups (Levasseur et al., 2015; Sanchez, 1999), reduced transportation and health costs (Sener et al., 2016; Victoria Transport Policy Institute, 2017), lower carbon emissions (Frank et al., 2010), better mental health (Martin et al., 2014), and greater transportation safety (Beck et al., 2007). Public-transit investment can also advance health equity, as low-income groups and people of color are the most frequent public-transit users (Pew Research Center, 2016) and also bear most of the negative externalities of private automobile dependency (World Health Organization, 2010).

In 2015, only 11% of Americans used public transit on a daily or weekly basis (Pew Research Center, 2016), and in 2016, only 5%

* Corresponding author. Department of Epidemiology, University of Washington School of Public Health, 1959 NE Pacific Street, Health Sciences Bldg, F-262, Box 357236, Seattle, WA 98195, USA.
E-mail address: jerzy@uw.edu (J. Eisenberg-Guyot).

https://doi.org/10.1016/j.jth.2019.100604
Received 2 May 2019; Received in revised form 19 July 2019; Accepted 23 July 2019
Available online 03 August 2019
2214-1405/

of U.S. workers commuted via public transit (American Public Transportation Association, 2017a). Barriers to higher transit use include lack of access to transit systems (Pucher, 1988; Transportation Research Board, 2001), fare costs (Mineta Transportation Institute, 2016; Perrotta, 2017), and transit services of inadequate scale, convenience, and accessibility, particularly for people with low incomes and disabilities (Federal Highway Administration, 2014; Lubitow et al., 2017). Nonetheless, transit ridership has increased in the U.S. over the last several decades (American Public Transportation Association, 2017a) after declining in the decades following World War II with suburbanization and the closing of some public-transit systems (U.S. Environmental Protection Agency, n.d.). From 2005 to 2015, total transit passenger miles traveled in the U.S. grew twice as fast as population size and three times as fast as total highway vehicle miles traveled (American Public Transportation Association, 2017a).

This study focused on transit use and walking behavior because research has repeatedly shown that among the non-physically-disabled, those who use transit ("transit users") walk more than people who do not use transit ("transit non-users") (Freeland et al., 2013; Saelens et al., 2014). This study's main objective was to explore *where* transit users walk, a topic that has received little attention in the literature. Understanding where transit users spend time engaging in active behaviors like walking could help identify ways to promote transit use and achieve its co-benefits. For example, it could be that using transit to get from home to work or work to home confines transit users' travel to the small areas around work or home. This could in part be driven by lack of access to a car. Alternatively, it could be that transit users want to walk further from their transit destinations, but poor pedestrian infrastructure outside their home and work neighborhoods limits them. Thus, improving pedestrian infrastructure in those neighborhoods may encourage more transit use and subsequent active travel (Beimborn et al., 2003). Likewise, improving pedestrian infrastructure within the home and work neighborhoods but not outside them may be an insufficient means of transit promotion.

Most research on where people walk – be it transit related or not – has been place-specific, covering a narrow range of locations, such as within home, work, downtowns, or retail neighborhoods (McCormack and Shiell, 2011; Voss et al., 2016). This spatially-limited focus is likely related to the short distances that many people are willing to walk to destinations, including to transit (Durand et al., 2016; Lachapelle and Pinto, 2016). Nonetheless, non-experimental observational studies that used objective physical activity (PA) data (i.e., accelerometer and/or GPS-measured data) have shown that moderate-to-vigorous PA (MVPA) like walking often occurs in a range of locations rather than in a single area (Dunton et al., 2008; Hurvitz et al., 2014). Moreover, one such studyfound that in addition to walking to access transit, transit use was associated with more walking to services near home and work (Lachapelle et al., 2011). Meanwhile, quasi-experimental observational studies using objective PA data have associated the introduction of light-rail transit (LRT) with a shift in the location of PA to areas around LRT stations (Huang et al., 2017; Miller et al., 2015). A recent meta-analysis of quasi-experimental studies found that LRT introduction was associated with reduced overall PA, but increased transit-related PA (Hirsch et al., 2018), while another found that LRT introduction was associated with increased light-to-moderate PA, but not increased MVPA (Xiao et al., 2019).

In our study, we used accelerometer- and GPS-measured PA data from the King County, Washington-based Travel Assessment and Community (TRAC) study to identify where transit users walked in relation to their home and work neighborhoods. To consider the effect of transit use, we compared walking durations on days when participants used transit with walking durations on days when they did not. In addition to durations of total walking, we analyzed durations of non-transit-related walking, because on transit days, transit users may walk to non-transit-related locations they would have otherwise accessed by car (Lachapelle et al., 2011; McAslan, 2017). We hypothesized that transit users would have greater durations of total walking and non-transit-related walking on transit days than on non-transit days, and that a substantial proportion of this greater duration would be due to activity beyond the home and work neighborhoods.

This research is critical, because targeting and implementing effective pedestrian-infrastructure interventions aimed at promoting transit use requires understanding where transit users actually walk.

2. Methods

2.1. Sample and data

2.1.1. Study overview

We used data on transit users from three waves of TRAC, a study conducted from 2008 to 2013 in King County, Washington. King County, which is in Western Washington, has approximately 2.2 million residents, one-third of whom reside in Seattle (King County Office of the Executive, 2018). King County has a LRT system that opened in 2009, as well an extensive bus network (City of Seattle Department of Transportation, 2016). In 2015, 21% of Seattle workers commuted to work by public transit, a higher proportion than in most major metropolitan areas (Schmitt, 2016).

TRAC's sampling frame included adults living in King County. We stratified the sampling frame to ensure roughly equal numbers of participants living less than one mile and more than one mile from future LRT stations, who lived in otherwise similar built environments with similar demographic characteristics (Moudon et al., 2009). We used parcel-based sampling to identify addresses within the sample frame, and identified households using reverse telephone directories. We contacted potential participants by telephone, and recruited them if they were age 20 or older, able to complete a travel diary and survey in English, and able to walk unassisted for ≥ 10 min. Participants consented to wear an accelerometer, carry a GPS data logger, and complete a place-based paper travel diary (based on the National Household Travel Survey instrument) for one week during each of the three assessment periods (Federal Highway Administration, 2009), as well as complete a sociodemographic survey. In the travel diaries, participants recorded names and addresses of places visited, primary activities, arrival and departure times, and the transportation mode used to travel between places. On the sociodemographic survey, participants reported gender, age, weight, height, household income (at $10,000 intervals), highest level of education, race/ethnicity, and employment characteristics (being employed outside the home or not and working full or part time).

We used different accelerometer and GPS devices across the three survey waves due to improvements in device technology. Regarding accelerometers, we used Actigraph (ActiGraph LLC, Fort Walton Beach, FL) GT1M in wave 1 and GT3M in waves 2 and 3. Regarding GPS data loggers, we used GlobalSat DG-100 (Taipei, Taiwan) in waves 1 and 2 and BT-Q1000-XT (QStarz, Taipei, Taiwan) in wave 3.

2.1.2. Processing walking behavior and location data

TRAC's data processing has been described elsewhere (Hurvitz et al., 2014; Kang et al., 2013). Briefly, we integrated data from the accelerometer, GPS device, and travel diary for each participant into "Lifelogs" by time matching GPS and travel-diary locations for each 30-s accelerometer epoch. Valid days had ≥1 location recorded in the travel diary, ≥ 1 GPS record, and an accelerometer wear time of ≥8 h. We considered continuous accelerometer periods of ≥60 min without activity – allowing for up to two consecutive minutes with accelerometry counts < 100 – as non-wear times (Matthews et al., 2008). We considered bouts of activity ≥5 min with accelerometer counts ≥500 per 30-s epoch as physical activity (allowing for 2 min of subthreshold accelerometer counts); we classified bouts as walking bouts based on GPS speeds (2–6 km/h), spatial configuration, and/or temporal overlap with trips recorded in the travel diary (Kang et al., 2013).

We assigned walking to six areas: within and beyond the home neighborhood, within and beyond the work neighborhood, and within and beyond the "home/work" neighborhood. (Fig. 1). The home and work neighborhoods were defined by radial buffers around participants' home and work geocoded addresses and were not mutually exclusive; activity occurring beyond home may have occurred within work (and vice versa). We chose 400 m and 800 m buffers because they are commonly used by researchers to approximate the range of distances pedestrians will walk to transit and other services (El-Geneidy et al., 2014; Yang and Diez-Roux, 2012). The combination of the home *and* work buffers comprised the home/work neighborhood; walking that occurred outside both the home *and* work buffers was considered "beyond" home/work, while walking that occurred inside either the home buffer *or* the work buffer was considered "within" home/work. Participants who lived less than 800 m from work had overlapping home and work buffers; for these participants, the area within their home/work neighborhood was less than the area within the home/work neighborhood for participants who lived at least 800 m from work.

Because walking inside one's home or workplace is unlikely to be associated with transit use, we excluded GPS data within 60 m of participants' home or work addresses to focus on walking that likely occurred outdoors. Although prior research found that approximately 75% of DG-100 GPS points and approximately 60% of BT-Q1000-XT GPS points fall within 20 m of an indoor device (Wu et al., 2010), we chose the more conservative threshold of 60 m after examining our data. To precisely allocate walking time to the four areas, we constructed line strings by connecting temporally adjacent GPS points within each bout (Open GIS Consortium, 1999). Geographic information system (GIS) overlay analysis split the line segments into sub-segments within or beyond the home or work buffers, yielding estimates of walking duration associated with each sub-segment on either side of the buffers (Fig. 2). We summed walking durations in minutes by participant-day (24 h) in each of the six areas. Finally, we classified walk bouts as being transit-related if they overlapped with or were within 10 min of a transit trip or transit place (e.g., bus stop, metro tunnel, or park and ride) as recorded in the travel log. We classified days with any transit-related walking as "transit days", and classified days with a place recorded as "work" in the travel log as "work days". We performed GIS data storage and analysis using PostgreSQL (The PostgreSQL Global Development Group, 2017) with the PostGIS spatial extension (The PostGIS Development Group, 2017).

2.1.3. Processing data on neighborhood characteristics

In each of the 400 m and 800 m home and work neighborhoods, we used residential and employment density and average daily bus ridership to capture neighborhood characteristics that support transit use and walking (Rodríguez et al., 2009; Taylor and Fink, 2003). Residential data came from parcel data collected by the King County Assessor. We estimated employment per parcel using data from the Washington State Employment Security Department by matching employment sector to parcel predominant land use and normalizing counts of employees by parcel area. Bus ridership data came from METRO, the County's transportation agency. The Urban Form Lab standardized and processed the neighborhood data and matched it to the correct study wave by year.

2.1.4. Study sample

Our primary analyses focused on "transit users": participants who recorded at least one "transit day" (a day with any transit-related walking) across the three assessment periods. Transit users comprised 54.4% of all TRAC participants. Additionally, because our analyses focused on home *and* work locations, we restricted our sample to participants who worked outside the home (71.6% of transit users), and only analyzed observation days on which those participants travelled to work ("workdays") (51.2% of transit users' total observations days). Results from analyses of the home locations that included the full sample of transit users on both workdays and non-workdays resembled results from the analyses presented below.

2.2. Primary analyses

2.2.1. Location and duration of total walking

We first calculated descriptive statistics to identify where transit users walked on transit days and non-transit days relative to each location (less than or at least 400 m or 800 m from home, work, or home/work).

Next, we sought to identify where changes in walking durations on transit days compared with non-transit days occurred. To this

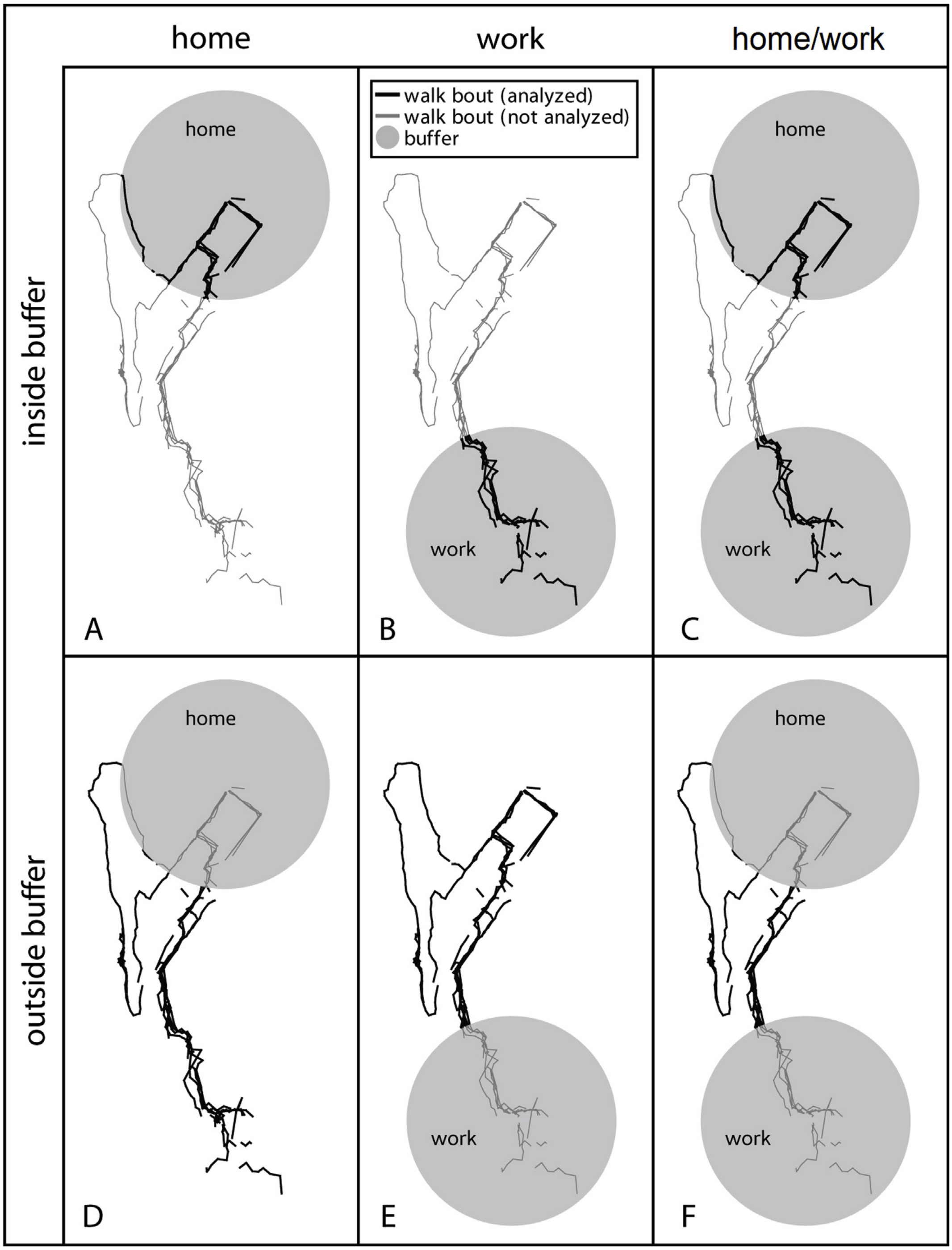

Fig. 1. Walking location schematic. Panels A and D show walking activity within and beyond the home neighborhood buffers. Panels B and E show walking activity within and beyond the work neighborhood buffers. Panels C and F show walking activity within and beyond the home/work neighborhood buffers.

end, we used "xtgee" in Stata 13 to estimate rate ratios of total minutes of walking per day on transit days compared with non-transit days in each location using Poisson generalized estimating equations (GEE) with person-level exchangeable correlation structure and cluster-robust standard errors. We treated the participant-day as the person-time contributed for each observation; thus, we did not specify an offset in the models. We fitted six models total. For the home locations, we estimated: 1) total minutes of walking less than 400 m from home and at least 400 m from home on transit days compared with non-transit days; and 2) total minutes of walking less than 800 m from home and at least 800 m from home on transit days compared with non-transit days (models 1 to 2). We then fitted

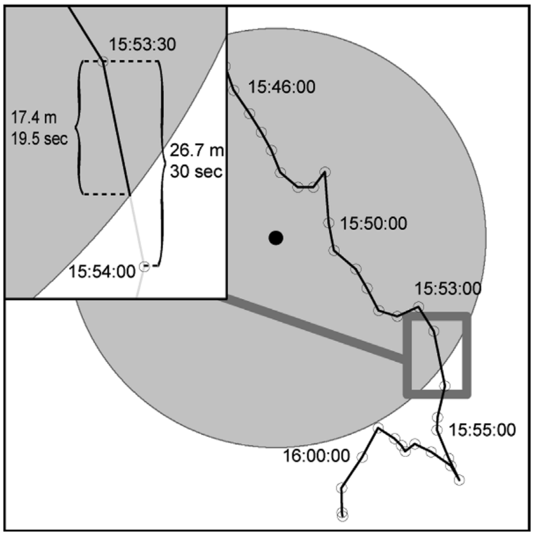

Fig. 2. Diagram showing how the duration of walking is measured when a walking bout crosses a buffer line. The shaded grey circle represents a 400 m or 800 m buffer centered around the home or work location (shown as a black dot); the solid black line is a line string linking the GPS points of a walking bout (GPS points at 30 s intervals are shown as light-grey circles).

analogous models for the work and home/work locations (models 3 to 6). To identify differences in the location of walking on transit days compared with non-transit days, we included transit day by buffer interaction terms in each of the models. The equation below displays the models' general structure:

$$Log\,(total\ minutes\ of\ walking)_{ij} = \beta_0 + \beta_1 transit\ day_{ij} + \beta_2 buffer_{ij} + \beta_3 transit\ day_{ij} * buffer_{ij} + \beta_4 covariates_{ij} + \varepsilon_{ij}$$

where:

Log(total minutes of walking)$_{ij}$ is the log of the total minutes of walking for participant i on observation day j
β_1 exponentiated is the covariate-adjusted ratio of the minutes of walking on transit days compared with non-transit days at least 400 m or 800 m from home, work, or home/work
$(\beta_1 + \beta_3)$ exponentiated is the covariate-adjusted ratio of the minutes of walking on transit days compared with non-transit days less than 400 m or 800 m from home, work, or home/work

We conceptualized transit use as having an additive rather than a multiplicative effect on daily minutes of walking. Therefore, we estimated rate differences from the GEE models using Stata's "margins" command (Williams, 2017). We calculated standard errors via the delta method.

For analyses focused on home-related locations, we *a priori* identified the following variables as potential confounders: race/ethnicity, gender, age, body mass index (BMI, kg/m^2), education, income, employment, year fixed effects, and within each 400 m or 800 m home buffer, employment density (employees per acre), residential density (units per acre), and bus ridership (mean daily transit boardings and alightings per acre). For analyses focused on the work- and home/work-related locations, we identified the same confounders. However, in analyses focused on work-related locations, neighborhood characteristics were measured in the work buffer rather than in the home buffer, while in analyses focused on home/work-related locations, neighborhood characteristics were measured in both the home buffer and in the work buffer. We included all confounders in the GEE models as covariates.

We adjusted for the neighborhood characteristics because, as measures of walkability, we hypothesized they were associated with the probability of using transit and causally related to walking duration (Rodríguez et al., 2009; Taylor and Fink, 2003). The variables were only measured within participants' home and work neighborhoods because they were assumed to be participants' primary exposure to neighborhood walkability. Furthermore, the neighborhood characteristics participants encountered within their home and work neighborhoods likely correlated with the neighborhood characteristics they encountered beyond them (Chaix et al., 2017).

2.2.2. Location and duration of non-transit-related walking

We next sought to identify the effect of a transit day on durations of walking in the various locations beyond its effects on walking to and from transit. Thus, we fit the GEE models described above with minutes of non-transit-related walking per day as the outcome rather than total minutes of walking per day. We classified walking bouts as non-transit-related if they did not overlap with a self-reported transit trip (or the 10 min before or after a transit trip) and did not include a self-reported location with a name consistent with transit use (e.g., bus stop, metro tunnel, or park and ride).

Table 1
Descriptive statistics for transit users in the study.

	n	%
Total	221	–
Male	133	60.2
Non-Hispanic white	177	80.1
College graduate	170	76.9
Work full-time	160	72.4
Annual household income		
< $50,000	86	38.9
$50,000-$100,000	84	38.0
> $100,000	51	23.1
BMI (kg/m^2)		
< 25.0	111	50.2
25.0–29.9	65	29.4
≥30.0	45	20.4
	Mean	**SD**
Age (years)	46.1	11.2

2.3. Secondary analyses: comparing transit users with transit non-users

We have previously shown that in this population, transit users on non-transit days walk similar durations to transit non-users (Saelens et al., 2014). In this study, we ran analyses to confirm these findings held in specific locations. Specifically, we used the GEE models to compare minutes of walking per day in the six locations for transit users on non-transit days with minutes of walking per day for transit non-users. In these models, “transit user” was the covariate of interest rather than “transit day”.

3. Results

3.1. Descriptive statistics

We conducted the analyses on a sample of 221 transit users who worked outside the home. Most identified as women (60.2%) and non-Hispanic white (80.1%), and had high socioeconomic status (SES), with 61.1% reporting incomes ≥ $50,000 per year, 76.9% reporting being college graduates, and most working fulltime (72.4%) (Table 1). Additionally, participants’ mean age was 46.1 years, and 50.2% reported BMIs less than 25.0.

3.2. Location and duration of total walking

We identified 803 of 1445 observation days (55.6%) as transit days. Transit users averaged more minutes of total walking on transit days than non-transit days in each location (Fig. 3). When considering the home and work neighborhoods separately, greater durations of total walking occurred beyond the two neighborhoods than within them on all days (i.e., on non-transit days and transit days). When considering the home and work neighborhoods jointly (by using the home/work buffer), at 400 m, a greater duration of total walking occurred beyond the joint neighborhood than within it on all days. However, at 800 m, a greater duration of total walking occurred within the joint neighborhood than beyond it on all days.

Table 2 displays results for the adjusted regression analyses focused on total walking. For the home locations, the greater duration of total walking on transit days was primarily due to increased activity beyond the home neighborhood. For example, less than 400 m from home, a transit day was associated with 4.1 more minutes of total walking than a non-transit day (95% CI: 2.6, 5.6), but at least 400 m from home, it was associated with 14.3 more minutes of total walking (95% CI: 10.7, 18.0).

Similarly, for the work locations, the greater duration of total walking on transit days was primarily due to increased activity beyond the work neighborhood (Table 2). For example, less than 400 m from work, a transit day was associated with 2.9 more minutes of total walking than a non-transit day (95% CI: 1.7, 4.1), but at least 400 m from work, it was associated with 16.1 more minutes of total walking (95% CI: 12.3, 19.9).

Nonetheless, analyses of the home/work locations revealed that much of the greater duration of total walking on transit days beyond the home neighborhood actually occurred within the work neighborhood (and vice versa) (Table 2). Less than 400 m from home/work, a transit day was associated with 7.8 more minutes of total walking than a non-transit day (95% CI: 5.9, 9.8), while at least 400 m from home/work, it was associated with 9.9 more minutes of total walking (95% CI: 6.9, 13.0). Meanwhile, less than 800 m from home/work, a transit day was associated with 12.9 more minutes of total walking than a non-transit day (95% CI: 9.8, 16.0), while at least 800 m from home/work, it was associated with 5.3 more minutes of total walking (95% CI: 3.1, 7.4).

3.3. Location and duration of non-transit-related walking

As with total walking, transit users averaged more minutes of non-transit-related walking on transit days than non-transit days in

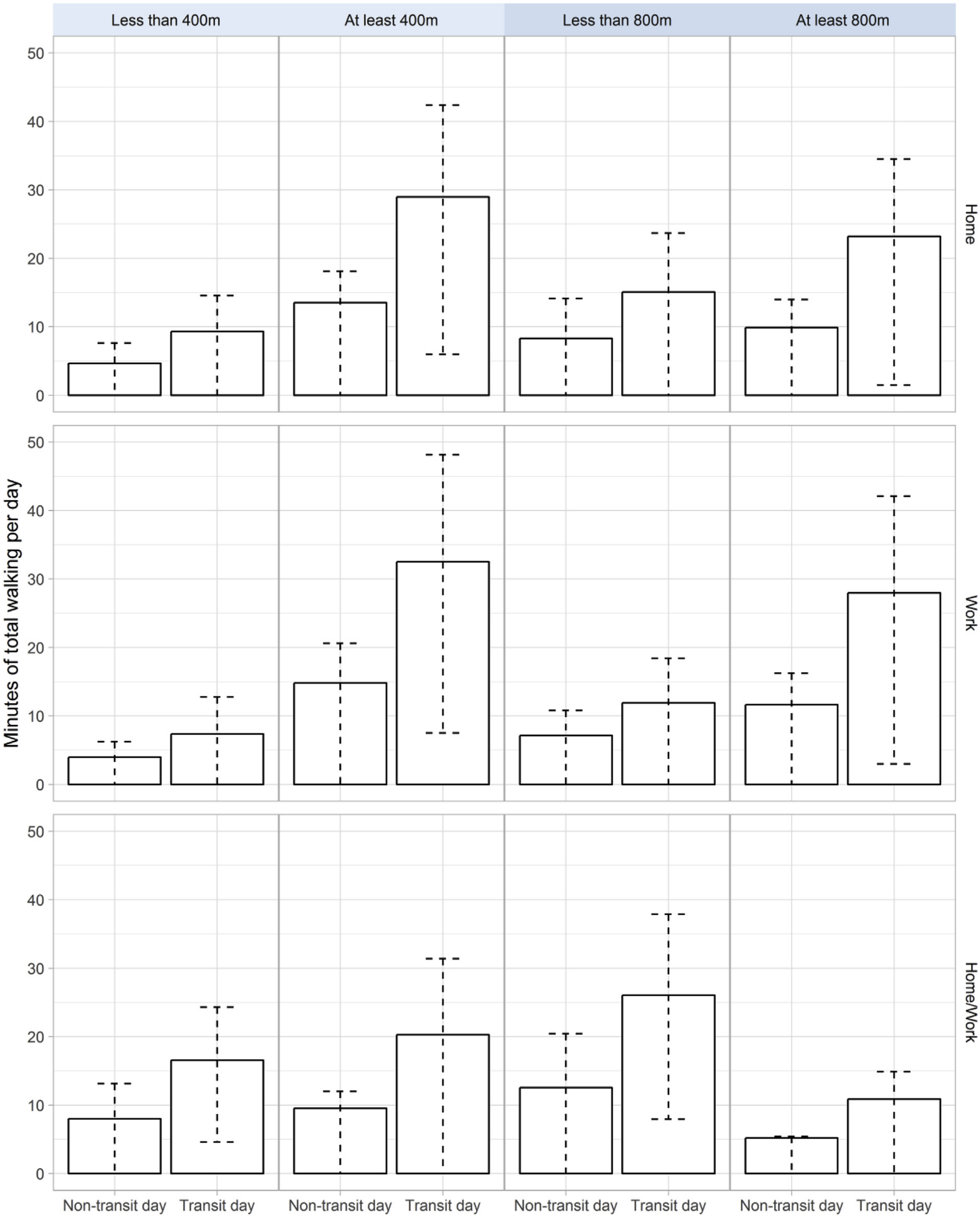

Fig. 3. Mean minutes per day of total walking in each location on non-transit days and transit days. Dotted bars display 25th and 75th percentiles.

each location (Fig. 4). Moreover, when considering the home and work neighborhoods separately, greater durations of non-transit-related walking occurred beyond the two neighborhoods than within them on all days. Similarly, when considering the neighborhoods jointly (by using the home/work buffer), at 400 m, a greater duration of non-transit-related walking occurred beyond the joint neighborhood than within it on all days. However, at 800 m, a greater duration of non-transit-related walking occurred within the

Table 2
Adjusted rate differences in minutes per day of total walking in each location on transit days compared with non-transit days.

	Rate difference (95% CI)[a]		
	Home[b]	Work[c]	Home/Work
400m locations			
< 400 m on transit day vs non-transit day	4.1 (2.6, 5.6)	2.9 (1.7, 4.1)	7.8 (5.9, 9.8)
≥400 m on transit day vs non-transit day	14.3 (10.7, 18.0)	16.1 (12.3, 19.9)	9.9 (6.9, 13.0)
800m locations			
< 800 m on transit day vs non-transit day	6.1 (3.6, 8.6)	4.1 (1.8, 6.3)	12.9 (9.8, 16.0)
≥800 m on transit day vs non-transit day	12.4 (9.3, 15.4)	15.0 (11.4, 18.6)	5.3 (3.1, 7.4)

Notes.
[a] Rate difference is an average marginal effect calculated from Poisson generalized estimating equations with person-level exchangeable correlation structure and cluster-robust standard errors. Sample size was 221 participants on 1445 observation days.

joint neighborhood than beyond it on all days.

Table 3 displays results for the adjusted regression analyses focused on non-transit-related walking. For the home locations, the greater duration of non-transit-related walking on transit days occurred almost entirely beyond the home neighborhood. For example, less than 400 m from home, a transit day was associated with 2.3 more minutes of non-transit-related walking than a non-transit day (95% CI: 1.1, 3.6), but at least 400 m from home, it was associated with 5.4 more minutes of non-transit-related walking (95% CI: 2.5, 8.3) (Table 2).

As in analyses focused on the home locations, in analyses focused on the work locations, the greater duration of non-transit-related walking on transit days occurred almost entirely beyond the work neighborhood (Table 3). For example, less than 400 m from work, a transit day was associated with just 1.6 more minutes of non-transit-related walking than a non-transit day (95% CI: 0.6, 2.6), but at least 400 m from work, it was associated with 5.6 more minutes of non-transit-related walking (95% CI: 2.5, 8.7).

Nonetheless, as with total walking, analyses of the home/work location revealed that much of the greater duration of non-transit-related walking on transit days beyond the home neighborhood actually occurred within the work neighborhood (and vice versa) (Table 3). Less than 400 m from home/work, a transit day was associated with 3.1 more minutes of non-transit-related walking than a non-transit day (95% CI: 1.5, 4.6), while at least 400 m from home/work, it was associated with 4.1 more minutes of non-transit-related walking (95% CI: 1.5, 6.6). Meanwhile, less than 800 m from home/work, a transit day was associated with 4.6 more minutes of non-transit-related walking than a non-transit day (95% CI: 2.2, 7.1), while at least 800 m from work, it was associated with 3.2 more minutes of walking (95% CI: 1.4, 5.0).

3.4. Transit users on non-transit days compared with transit non-users

Table A.1 in the appendix displays results for the adjusted regression analyses comparing walking among transit users on non-transit days with walking among transit non-users. Analyses revealed that, overall, being a transit user on a non-transit day was not associated with more minutes of walking per day than being a transit non-user. Furthermore, there were minimal differences between the groups in minutes of walking per day in each of the locations.

4. Discussion

We used GPS and accelerometer data to analyze where transit users walked as they moved through their daily lives. When considering the home and work neighborhoods separately, we found that greater durations of total walking and non-transit-related walking on transit days were primarily due to walking beyond those neighborhoods. Similarly, when considering the home and work neighborhoods jointly, we found that at 400 m, most of the greater duration of total walking on transit days was due to walking beyond the joint neighborhood. However, at 800 m, the greater duration of total walking on transit days was primarily due to walking within the joint neighborhood. Meanwhile, the greater duration of non-transit-related walking on transit days was distributed relatively evenly within and beyond the home/work neighborhood. Finally, the duration of walking for transit users on non-transit days resembled that of transit non-users, suggesting that transit use added to baseline activity rather than replacing it, as shown in prior research in this population (Saelens et al., 2014). Furthermore, transit users' walking locations on non-transit days did not differ substantially from transit non-users' walking locations.

Given the buffer's large area, particularly for participants who lived more than 800 m from work ($\sim 4\,km^2$), it is unsurprising that at 800 m, most of the greater duration of total walking and non-transit-related walking on transit days occurred within the home/work neighborhood. Nonetheless, despite the 800 m buffer's area, there was a non-trivial increase in total walking and non-transit-related walking beyond the home/work neighborhood on transit days. Moreover, on the relative risk (RR) scale, the greater durations of total walking (RR: ∼2.0) and non-transit-related walking (RR: ∼1.5) were similar beyond and within the 800 m home/work neighborhood.

The considerable amount of total walking and non-transit-related walking occurring outside the home and work neighborhoods, as well as the influence of transit use on walking locations, is broadly consistent with prior research (Huang et al., 2017; Hurvitz

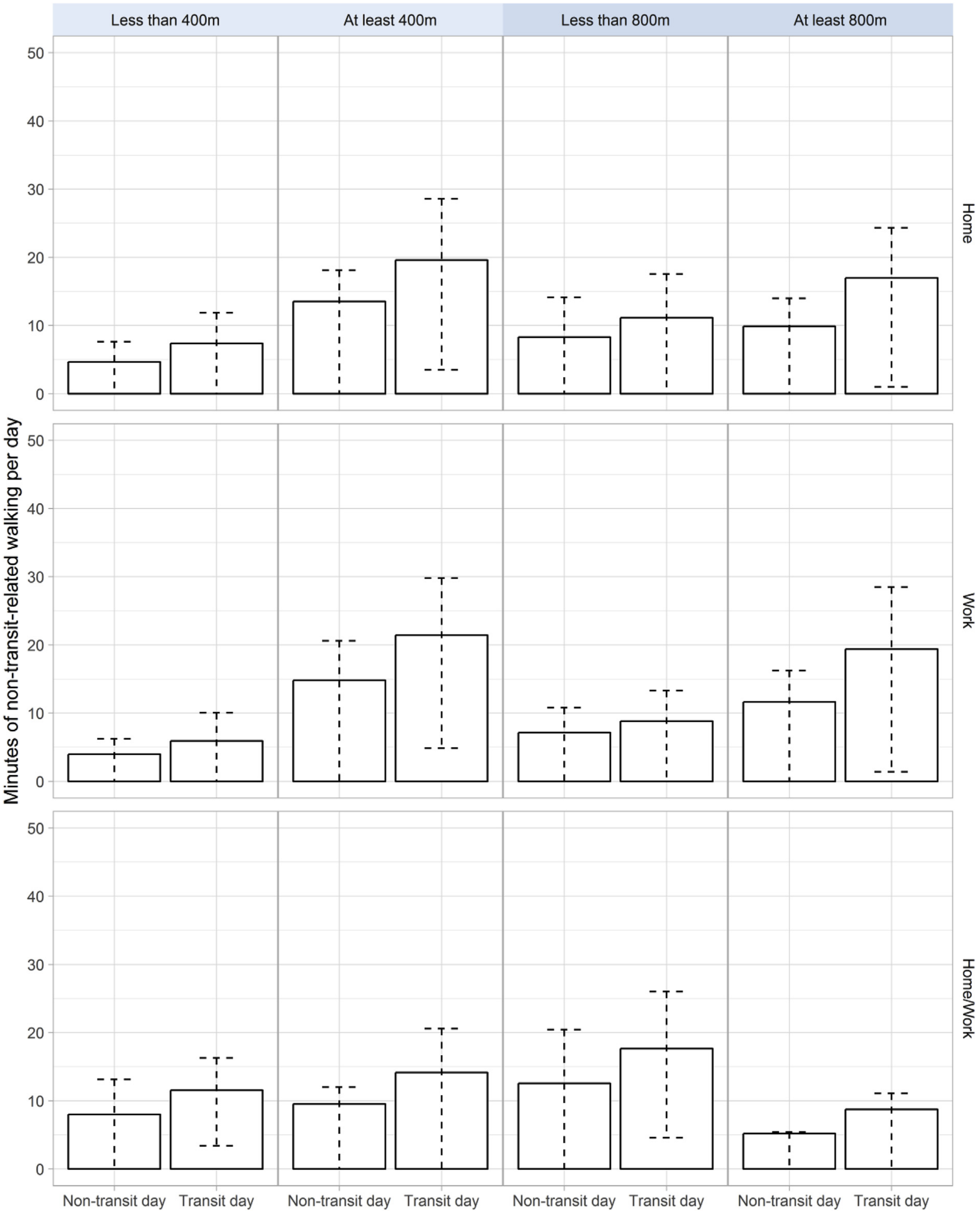

Fig. 4. Mean minutes per day of non-transit-related walking in each location on non-transit days and transit days. Dotted bars display 25th and 75th percentiles.

et al., 2014; Miller et al., 2015). Meanwhile, the greater duration of non-transit-related walking on transit days within the home/work neighborhood is consistent with some prior research on the topic. For example, Lachapelle et al. found that transit use correlated with more walking to services near home and work (Lachapelle et al., 2011). Nonetheless, their results may not be directly comparable

Table 3
Adjusted rate differences in minutes per day of non-transit-related walking in each location on transit days compared with non-transit days.

	Rate difference (95% CI)[a]		
	Home	Work	Home/Work
400m locations			
< 400 m on transit day vs non-transit day	2.3 (1.1, 3.6)	1.6 (0.6, 2.6)	3.1 (1.5, 4.6)
≥400 m on transit day vs non-transit day	5.4 (2.5, 8.3)	5.6 (2.5, 8.7)	4.1 (1.5, 6.6)
800m locations			
< 800 m on transit day vs non-transit day	2.1 (0.0, 4.1)	1.2 (−0.5, 2.8)	3.2 (1.4, 5.0)
≥800 m on transit day vs non-transit day	6.1 (3.6, 8.6)	6.9 (4.1, 9.7)	4.6 (2.2, 7.1)

Notes.
[a] Rate difference is an average marginal effect calculated from Poisson generalized estimating equations with person-level exchangeable correlation structure and cluster-robust standard errors. Sample size was 221 participants on 1445 observation days.

with ours because they did not identify walking locations using GPS, and trip purpose did not come from a travel diary; instead, the investigators surveyed participants about how many times in the previous month they walked to a given place from home or work (Lachapelle et al., 2011). In another study, Saelens et al. did not find that non-transit-related walking increased on transit days (Saelens et al., 2014). However, they did not run confounder-adjusted analyses, nor did they analyze the location of non-transit-related walking.

Readers may be concerned that poor transit access contributed to the substantial duration of walking beyond the home/work neighborhood on transit days; that is, transit users may have needed to walk far from home and work to access transit (or vice versa). However, 68% of Seattle residents live within a ½ mile of a frequently-served transit stop (City of Seattle Department of Transportation, 2016) and prior research suggests transit users rarely walk much more than a half mile to and from transit (El-Geneidy et al., 2014; Huang et al., 2017). Thus, the 800 m buffer should have captured the bulk of transit-related walking that originated or terminated at home or work.

Notably, not all the greater duration of walking on transit days was transit related. On transit days, transit users may have accessed destinations or activities by walking they would otherwise have accessed by car, such as public services, social engagements, or errands (Lachapelle et al., 2011). Alternatively, the need to access such destinations or activities may have affected travel-mode choice. That is, a participant may have taken transit to work one day because they planned an activity later in an adjacent, walkable neighborhood and did not want to be burdened by driving (McAslan, 2017). Our travel logs did not include motivation for travel mode choice; thus, we cannot distinguish these scenarios in our data. However, we performed additional analyses of the travel-log data to identify the types of places most commonly visited by transit users beyond the home/work neighborhood (details in Appendix A.2). Results showed that on non-transit days, participants most often visited grocery and non-grocery retail stores, while on transit days they most often visited restaurants and pubs (excluding transit stops, the most frequently visited place on transit days). This suggests that trip destination outside the home/work neighborhood may determine travel mode choice: on non-transit days, participants most often did retail and grocery shopping, which may be more conveniently done by car, while on transit days, participants most often ate at a restaurant or pub, which may be more conveniently done by foot or public transit (Clifton, 2004; Jackson and Owens, 2011; Jiao et al., 2011). In addition to facilitating access to services and social occasions (Kamruzzaman et al., 2016), public transit may lead to socializing between transit users during the transit ride itself, including between often segregated demographic and socioeconomic groups (Currie and Stanley, 2008).

5. Strengths and limitations

Our study had several strengths. First, unlike much prior research, we spatially located activity using objective GPS data rather than self-reported data, the latter of which is more prone to bias (Brondeel et al., 2015; Chaix, 2018; Oliver et al., 2010). Second, we identified walking bouts by integrating GPS, accelerometry, and travel diary data, which is superior to using travel-diary data alone (Kang et al., 2013). Third, we were well-powered to detect true differences in durations and locations of walking. Finally, to our knowledge, this is the first study that has used objective data to examine both where and for how long transit users walk on transit days and non-transit days.

The study limitations included first, a sample drawn from only one metropolitan area, King County, which has a higher level of transit mode share and more complete transit access than many US metropolitan areas (Schmitt, 2016). Moreover, participants had higher SES than most transit users nationally (American Public Transportation Association, 2017b). These factors may limit the generalizability of the results to other populations. Nonetheless, we have no data that suggests that transit users in King County have substantially different mobility patterns than transit users elsewhere.

Second, our use of Euclidean buffers rather than network buffers may also have limited our results' generalizability. In settings with lower street connectivity than King County, such as rural areas, pedestrians may need to walk farther to reach destinations inside or outside the buffers than pedestrians in urban areas. However, we did not construct the buffers using network distances for two primary reasons. First, pedestrians do not always walk along street networks; thus, network distances may not accurately capture travel distances for pedestrians, particularly in cities with many parks and large parcels (Chin et al., 2008; Tal and Handy, 2012). On average in our study, participants had two parks that overlapped with each of their 400 m home and work buffers and nearly six parks that overlapped with each of their 800 m home and work buffers. Second, Euclidean buffers are more conservative than network buffers. Because network buffers generate smaller areas than Euclidean buffers, a study using network buffers would have identified *more* walking occurring beyond the home and work neighborhoods than our study. Thus, our finding that a substantial proportion of walking on transit days occurred beyond the home and work neighborhoods would only be more-strongly supported by a similar study using network buffers.

Third, our analyses of non-transit-related walking did not distinguish utilitarian from recreational walking, activity types that often occur in different locations and for different durations (Kang et al., 2017), and which are influenced by different built-environment factors (Saelens and Handy, 2010).

Fourth, our analyses only included walking data that had GPS measurement; it did not consider walking that may have occurred but lacked GPS data. GPS data may be missing for several reasons: (1) the participant was active but the device was powered off due to being uncharged, (2) the participant was active, the device was on, but it was not receiving radio signals from satellites, or (3) the participant was inactive and the device was powered off, which would not result in any bias. Regarding (1), non-recording time due to a lack of charge should be minimal, as one charge lasts at least 24 h. Regarding (2), no evidence suggests that participants would be more or less likely to lose signal on transit days than non-transit days.

Finally, we calculated BMI using self-reported height and weight, which is subject to measurement error (Merrill and Richardson, 2009). However, given our large effect sizes, as well as the relatively even distribution of BMI across transit days and non-transit days in our sample, it is unlikely that correcting the measurement error in the BMI covariate would have an appreciable effect on our estimates.

6. Conclusion

This study used objective data to identify where transit users walked on transit days relative to non-transit days. We found that durations of total walking and non-transit-related walking were greater on transit days, and that when considering each of the neighborhoods in isolation, the greater durations of walking were primarily due to activity beyond the home or work neighborhoods. Similarly, when considering the neighborhoods jointly, at 400 m, most of the greater duration of walking occurred beyond the home/work neighborhood, although at 800 m, most of the greater duration of walking occurred within the home/work neighborhood.

Our results have several implications. First, much prior research, policymaking, and advocacy regarding transit use and pedestrian activity have focused on the home and work neighborhoods at the expense of locations outside them (McCormack and Shiell, 2011). Because we found that transit use correlated with walking beyond these neighborhoods, strategies to improve walkability and facilitate increased transit use – among those only using transit occasionally and among those not yet using it – must consider locations beyond the home and work neighborhoods, in addition to locations within them. Furthermore, public-health research on the relationship between transit use, walking, and built-environment characteristics should consider the characteristics of environments inside *and* outside the home and work neighborhoods. Finally, because durations of non-transit-related walking were greater on transit days outside participants' home and work neighborhoods, transit may help transit users access needs aside from travelling to and from home or work, such as services or social occassions, that they would have otherwise accessed by car.

Our analyses suggest several areas that should be explored in future research. First, because transit users walk extensively beyond the home and work neighborhoods, research should identify characteristics of those neighborhoods that facilitate or impede transit usage and walking. Second, research should explore in more detail the services and facilities transit users access, by foot or transit, outside the home and work neighborhoods; this information could be used by transit agencies to improve transit's utility to the public. Finally, research should examine the relationship between transit use and mobility in other metropolitan areas with different demographics, climate, and infrastructure.

Funding

This study was funded by the National Heart, Lung, and Blood Institute of the National Institutes of Health (award R01HL091881) and by the Washington Transportation Center (TransNow Research Project Agreement No. 61-7318).

Appendix

A.1 Location and duration of total walking among transit users on non-transit days compared with transit non-users

Table A.1
Adjusted rate differences in minutes per day of walking in each location for transit users on non-transit days compared with transit non-users.

	Rate difference (95% CI)[a]		
	Home[b]	Work[c]	Home/Work
400m locations			
< 400 m on transit day vs non-transit day	0.5 (−0.9, 1.8)	1.5 (0.1, 2.9)	1.9 (0.1, 3.8)

(*continued on next page*)

Table A.1 (*continued*)

	Rate difference (95% CI)[a]		
	Home[b]	Work[c]	Home/Work
≥400 m on transit day vs non-transit day	0.5 (−2.8, 3.8)	0.2 (−3.4, 3.8)	−1.1 (−4.1, 1.8)
800m locations			
< 800 m on transit day vs non-transit day	0.6 (−1.5, 2.7)	2.9 (0.8, 5.1)	1.7 (−0.8, 4.2)
≥800 m on transit day vs non-transit day	−0.2 (−3.1, 2.8)[a]	−1.4 (−4.8, 2.0)[a]	−1.7 (−4.1, 0.6)[a]

Notes.
[a] Rate difference is an average marginal effect calculated from Poisson generalized estimating equations with person-level exchangeable correlation structure and cluster-robust standard errors. Sample size was 301 participants on 1600 observation days.

A.2 Place types visited by transit users on non-transit days and transit days

We used the Lifelogs to identify the five most commonly visited places by transit users 400 m and 800 m beyond home/work on non-transit days and transit days. To this end, we categorized places recorded in the Lifelogs into one of fourteen place types: airport, ferry, gym/pool, medical, other (ambiguous place name or address), park, parking, public service (e.g., library), religious, restaurant/pub, retail – grocery/convenience, retail – other (e.g., mall), school, social/entertainment (e.g., concert). We then summed and ranked the counts of each place type in each buffer location on non-transit days and transit days (Table A2).

Table A.2
Five most commonly visited place types 400m and 800m beyond home/work on non-transit days and transit days.

400m buffer		
Rank	Non-transit day	Transit day
1	Retail – grocery/convenience	Other
2	Retail – other	Restaurant/pub
3	Restaurant/pub	Retail – grocery/convenience
4	Other	Retail – other
5	Social/entertainment	School
800m buffer		
Rank	Non-transit day	Transit day
1	Retail – grocery/convenience	Other
2	Retail – other	Restaurant/pub
3	Other	Retail – grocery/convenience
4	Restaurant/pub	Retail – other
5	Social/entertainment	Social/entertainment

Notes.
On transit days, "transit stop" was the most commonly visited place type, which we excluded from this summary.

References

American Public Transportation Association, 2017. 2016 Public Transportation Fact Book. (Washington D.C).

American Public Transportation Association, 2017. Who Rides Public Transportation. (Washington D.C).

Beck, L.F., Dellinger, A.M., O'Neil, M.E., 2007. Motor vehicle crash injury rates by mode of travel, United States: using exposure-based methods to quantify differences. Am. J. Epidemiol. 166, 212–218. https://doi.org/10.1093/aje/kwm064.

Beimborn, E., Greenwald, M., Jin, X., 2003. Accessibility, connectivity, and captivity: impacts on transit choice. Transp. Res. Rec. J. Transp. Res. Board 1835, 1–9. https://doi.org/10.3141/1835-01.

Brondeel, R., Pannier, B., Chaix, B., 2015. Using GPS, GIS, and accelerometer data to predict transportation modes. Med. Sci. Sport. Exerc. 47, 2669–2675. https://doi.org/10.1249/MSS.0000000000000704.

Brown, B.B., Werner, C.M., Tribby, C.P., Miller, H.J., Smith, K.R., 2015. Transit use, physical activity, and body mass index changes: objective measures associated with complete street light-rail construction. Am. J. Public Health 105, 1468–1474. https://doi.org/10.2105/AJPH.2015.302561.

Chaix, B., 2018. Mobile sensing in environmental health and neighborhood research. Annu. Rev. Public Health 39, 367–384. https://doi.org/10.1146/annurev-publhealth-040617-013731.

Chaix, B., Duncan, D., Vallée, J., Vernez-Moudon, A., Benmarhnia, T., Kestens, Y., 2017. The "residential" effect fallacy in neighborhood and health studies. Epidemiology 28, 789–797. https://doi.org/10.1097/EDE.0000000000000726.

Chin, G.K.W., Van Niel, K.P., Giles-Corti, B., Knuiman, M., 2008. Accessibility and connectivity in physical activity studies: the impact of missing pedestrian data. Prev. Med. (Baltim). 46, 41–45. https://doi.org/10.1016/j.ypmed.2007.08.004.

City of Seattle Department of Transportation, 2016. Transit Master Plan. (Seattle).

Clifton, K.J., 2004. Mobility strategies and food shopping for low-income families: a case study. J. Plan. Educ. Res. 23, 402–413. https://doi.org/10.1177/0739456X04264919.

Currie, G., Stanley, J., 2008. Investigating links between social capital and public transport. Transp. Rev. 28, 529–547. https://doi.org/10.1080/01441640701817197.

Dunton, G.F., Berrigan, D., Ballard-Barbash, R., Graubard, B.I., Atienza, A.A., 2008. Social and physical environments of sports and exercise reported among adults in the American Time Use Survey. Prev. Med. (Baltim). 47, 519–524. https://doi.org/10.1016/j.ypmed.2008.07.001.

Durand, C.P., Tang, X., Gabriel, K.P., Sener, I.N., Oluyomi, A.O., Knell, G., Porter, A.K., Hoelscher, D.M., Kohl, H.W., 2016. The association of trip distance with walking to reach public transit: data from the California Household Travel Survey. J. Transp. Heal. 3, 154–160. https://doi.org/10.1016/j.jth.2015.08.007.

El-Geneidy, A., Grimsrud, M., Wasfi, R., Tétreault, P., Surprenant-Legault, J., 2014. New evidence on walking distances to transit stops: identifying redundancies and gaps using variable service areas. Transportation (Amst). 41, 193–210. https://doi.org/10.1007/s11116-013-9508-z.
Federal Highway Administration, 2014. Mobility Challenges for Housholds in Poverty. (Washington D.C).
Federal Highway Administration, 2009. NHTS Field Documents and Travel Survey. (Washington D.C).
Frank, L.D., Greenwald, M.J., Winkelman, S., Chapman, J., Kavage, S., 2010. Carbonless footprints: promoting health and climate stabilization through active transportation. Prev. Med. (Baltim). 50, S99–S105. https://doi.org/10.1016/j.ypmed.2009.09.025.
Freeland, A.L., Banerjee, S.N., Dannenberg, A.L., Wendel, A.M., 2013. Walking associated with public transit: moving toward increased physical activity in the United States. Am. J. Public Health 103, 536–542. https://doi.org/10.2105/AJPH.2012.300912.
Hirsch, J.A., DeVries, D.N., Brauer, M., Frank, L.D., Winters, M., 2018. Impact of new rapid transit on physical activity: a meta-analysis. Prev. Med. Reports 10, 184–190. https://doi.org/10.1016/j.pmedr.2018.03.008.
Huang, R., Moudon, A.V., Zhou, C., Stewart, O.T., Saelens, B.E., 2017. Light rail leads to more walking around station areas. J. Transp. Heal. 6. https://doi.org/10.1016/j.jth.2017.02.002.
Hurvitz, P.M., Moudon, A.V., Kang, B., 2014. How far from home? The locations of physical activity in an urban U.S. setting. Prev. Med. (Baltim). 69, 181–186. https://doi.org/10.1016/j.ypmed.2014.08.034.
Jackson, C.K., Owens, E.G., 2011. One for the road: public transportation, alcohol consumption, and intoxicated driving. J. Public Econ. 95, 106–121. https://doi.org/10.1016/j.jpubeco.2010.09.010.
Jiao, J., Moudon, A., Drewnowski, A., 2011. Grocery shopping: how individuals and built environments influence choice of travel mode. Transp. Res. Rec. J. Transp. Res. Board 2230, 85–95. https://doi.org/10.3141/2230-10.
Kamruzzaman, M., Yigitcanlar, T., Yang, J., Mohamed, M.A., 2016. Measures of transport-related social exclusion: a critical review of the literature. Sustainability 8. https://doi.org/10.3390/su8070696.
Kang, B., Moudon, A.V., Hurvitz, P.M., Reichley, L., Saelens, B., 2013. Walking objectively measured: classifying accelerometer data with GPS and travel diaries. Med. Sci. Sport. Exerc. 45, 1419–1428. https://doi.org/10.1249/MSS.0b013e318285f202.
Kang, B., Moudon, A.V., Hurvitz, P.M., Saelens, B.E., 2017. Differences in behavior, time, location, and built environment between objectively measured utilitarian and recreational walking. Transp. Res. D Transp. Environ. 57, 185–194. https://doi.org/10.1016/j.trd.2017.09.026.
King County Office of the Executive, 2018. Demographics. [WWW Document]. https://www.kingcounty.gov/depts/executive/performance-strategy-budget/regional-planning/Demographics.aspx.
Lachapelle, U., Frank, L., Saelens, B.E., Sallis, J.F., Conway, T.L., 2011. Commuting by public transit and physical activity: where you live, where you work, and how you get there. J. Phys. Act. Health 8, S72–S82.
Lachapelle, U., Pinto, D.G., 2016. Longer or more frequent walks: examining the relationship between transit use and active transportation in Canada. J. Transp. Heal. 3, 173–180. https://doi.org/10.1016/j.jth.2016.02.005.
Levasseur, M., Cohen, A.A., Dubois, M., Généreux, M., Richard, L., Therrien, F., 2015. Environmental factors associated with social participation of older adults living in metropolitan, urbam and rural areas: the NuAge study. Am. J. Public Health 105, 1718–1725. https://doi.org/10.2105/AJPH.2014.302415.
Lubitow, A., Rainer, J., Bassett, S., 2017. Exclusion and vulnerability on public transit: experiences of transit dependent riders in Portland, Oregon. Mobilities 1–14. https://doi.org/10.1080/17450101.2016.1253816.
Martin, A., Goryakin, Y., Suhrcke, M., 2014. Does active commuting improve psychological wellbeing? Longitudinal evidence from eighteen waves of the British Household Panel Survey. Prev. Med. (Baltim). 69, 296–303. https://doi.org/10.1016/j.ypmed.2014.08.023.
Matthews, C.E., Chen, K.Y., Freedson, P.S., Buchowski, M.S., Beech, M., Pate, R.R., Troiano, R.P., 2008. Amount of time spent in sedentary behaviors in the United States, 2003-2004. Am. J. Epidemiol. 167, 875–881. https://doi.org/10.1093/aje/kwm390.
McAslan, D., 2017. Walking and transit use behavior in walkable urban neighborhoods. Michigan J. Sustain. 5, 51–72. https://doi.org/10.3998/mjs.12333712.0005.104.
McCormack, G.R., Shiell, A., 2011. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int. J. Behav. Nutr. Phys. Act. 8, 1–11. https://doi.org/10.1186/1479-5868-8-125.
Merrill, R.M., Richardson, J.S., 2009. Validity of self-reported height, weight, and body mass index: findings from the National Health and Nutrition Examination Survey, 2001-2006. Prev. Chronic Dis. 6, 1–10.
Miller, H.J., Tribby, C.P., Brown, B.B., Smith, K.R., 2015. Public transit generates new physical activity: evidence from individual GPS and accelerometer data before and after light rail construction in a neighborhood of Salt Lake City, Utah, USA. Health Place 36, 8–17. https://doi.org/10.1016/j.healthplace.2015.08.005.
Mineta Transportation Institute, 2016. Exploring Bicycle and Public Transit Use by Low-Income Latino Immigrants: a Mixed-Methods Study in the San Francisco Bay Area.
Moudon, A.V., Saelens, B., Rutherford, S., Hallenbeck, M., 2009. A Report on Participant Sampling and Recruitment for Travel and Physical Activity Data Collection.
Oliver, M., Badland, H., Mavoa, S., Duncan, M.J., Duncan, S., 2010. Combining GPS, GIS, and accelerometry: methodological issues in the assessment of location and intensity of travel behaviors. J. Phys. Act. Health 7, 102–108. https://doi.org/10.1123/jpah.7.1.102.
Open GIS Consortium, 1999. Open GIS Simple Features Specification for SQL Revision. 1.1.
Perrotta, A.F., 2017. Transit fare affordability: findings from a qualitative study. Public Works Manag. Policy 22, 226–252. https://doi.org/10.1177/1087724X16650201.
Pew Research Center, 2016. Who Relies on Public Transit in the U.S. [WWW Document]. http://www.pewresearch.org/fact-tank/2016/04/07/who-relies-on-public-transit-in-the-u-s/ accessed 4.23.18.
Pucher, J., 1988. Urban travel behavior as the outcome of public policy: the example of modal-split in Western Europe and North America. J. Am. Plan. Assoc. 54, 509–520. https://doi.org/10.1080/01944368808976677.
Rodríguez, D.A., Evenson, K.R., Diez Roux, A.V., Brines, S.J., 2009. Land use, residential density, and walking: the Multi-Ethnic Study of Atherosclerosis. Am. J. Prev. Med. 37, 397–404. https://doi.org/10.1016/j.amepre.2009.07.008.
Saelens, B.E., Handy, S.L., 2010. Built enviroment correlates of walking: a review. Med. Sci. Sport. Exerc. 40, S550–S566. https://doi.org/10.1249/MSS.0b013e31817c67a4.
Saelens, B.E., Moudon, A.V., Kang, B., Hurvitz, P.M., Zhou, C., 2014. Relation between higher physical activity and public transit use. Am. J. Public Health 104, 854–859. https://doi.org/10.2105/AJPH.2013.301696.
Sanchez, T.W., 1999. The connection between public transit and employment: the cases of Portland and Atlanta. J. Am. Plan. Assoc. 65, 284–296. https://doi.org/10.1080/01944369908976058.
Schmitt, A., 2016. Where car commuting is shrinking and where it's not. [WWW Document]. Streets Blog USA. http://usa.streetsblog.org/2016/09/16/where-car-commuting-is-shrinking-and-where-its-not/ accessed 12.9.17.
Sener, I.N., Lee, R.J., Elgart, Z., 2016. Potential health implications and health cost reductions of transit-induced physical activity. J. Transp. Heal. 3, 133–140. https://doi.org/10.1016/j.jth.2016.02.002.
Tal, G., Handy, S., 2012. Measuring nonmotorized accessibility and connectivity in a robust pedestrian network. Transp. Res. Rec. J. Transp. Res. Board 2299, 48–56. https://doi.org/10.3141/2299-06.
Taylor, B.D., Fink, C.N., 2003. The Factors Influencing Transit Ridership: a Review and Analysis of the Ridership Literature. (Berkeley).
The PostGIS Development Group, 2017. PostGIS.
The PostgreSQL Global Development Group, 2017. PostgreSQL.
Transportation Research Board, 2001. Making Transit Work: Insight from Western Europe, Canada, and the United States - Special Report 257. (Washington D.C).
U.S. Environmental Protection Agency, n.d., History of reducing air pollution from transportation in the United States. [WWW Document]. https://www.epa.gov/air-pollution-transportation/accomplishments-and-success-air-pollution-transportation.
Victoria Transport Policy Institute, 2017. Evaluating Public Transit Benefits and Costs.

Voss, C., Sims-Gould, J., Ashe, M.C., McKay, H.A., Pugh, C., Winters, M., 2016. Public transit use and physical activity in community-dwelling older adults: combining GPS and accelerometry to assess transportation-related physical activity. J. Transp. Heal. 3, 191–199. https://doi.org/10.1016/j.jth.2016.02.011.
Williams, R., 2017. Using Stata's Margins Command to Estimatte and Interpret Adjusted Predictions and Marginal Effects.
World Health Organization, 2010. Unmasking and Overcoming Health Inequities in Urban Settings. UN Habitat, Geneva. https://doi.org/10.1373/clinchem.2011.163634.
Wu, J., Jiang, C., Liu, Z., Houston, D., Jaimes, G., McConnell, R., 2010. Performances of different global positioning system devices for time-location tracking in air pollution epidemiological studies. Environ. Health Insights 4, 93–108. https://doi.org/10.4137/EHI.S6246.
Xiao, C., Goryakin, Y., Cecchini, M., 2019. Physical activity levels and new public transit: a systematic review and meta-analysis. Am. J. Prev. Med. 56, 464–473. https://doi.org/10.1016/j.amepre.2018.10.022.
Yang, Y., Diez-Roux, A.V., 2012. Walking distance by trip purpose and population subgroups. Am. J. Prev. Med. 43, 11–19. https://doi.org/10.1016/j.amepre.2012.03.015.