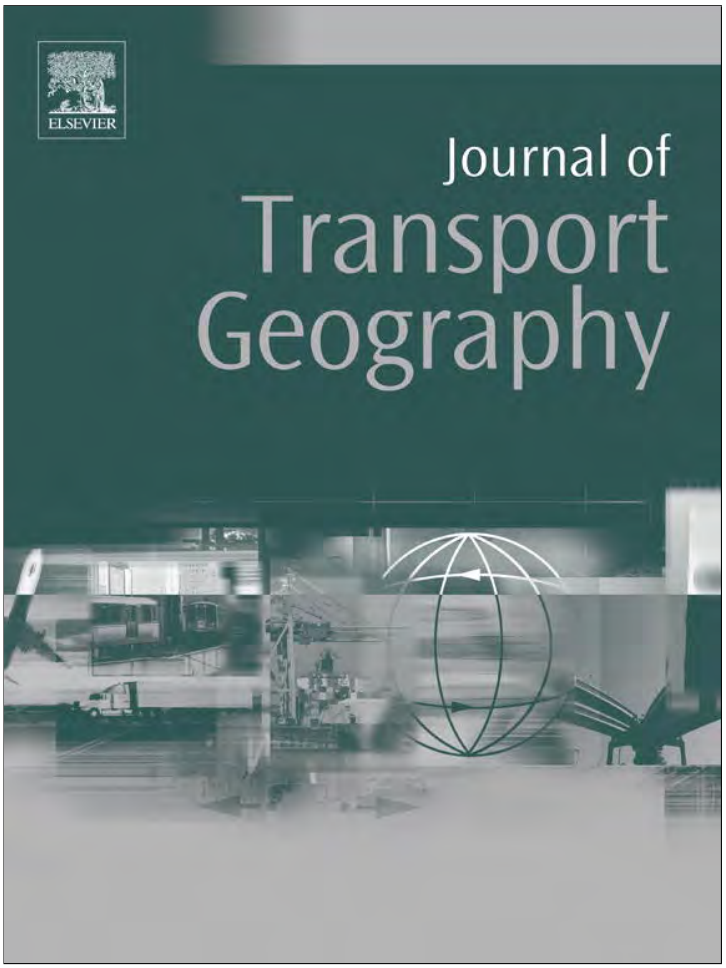

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Active-transport walking behavior: destinations, durations, distances

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ABSTRACT

This paper fills a gap in our knowledge of active-transport (AT) walking, by presenting detailed aspects of walking behavior for a medium-sized North American city. It analyzes the frequency and length of walking episodes, categorized by origins, purposes, and destinations, and also investigates distance-decay functions for major destinations. The study employs day-after recall time diary and questionnaire data from the 2007–8 Space–Time Activity Research (STAR) survey conducted in Halifax, Canada. GPS co-ordinate data enhanced the accuracy of location information, start times, and end times of the 1790 AT walking episodes, while GIS software was used to compute a shortest-path distance between the origin and destination of each episode.

Home is both the most common origin and destination for AT walks, and the most common purpose is travel-to-shop rather than travel-to-work. Most walks are to non-home locations, such as retail establishments and offices. Particularly important are restaurants and bars, grocery stores, shopping centers, banks, and other services. All major destinations show strong distance-decay effects: most walks are shorter than 600 m, and very few exceed 1200 m. The assumption employed in the walkability literature, that one should restrict the 'neighborhood of opportunity' to walking destinations within 1000 m of the home, is seen to be well justified. However, a planning policy focus on the walker's home neighborhood is revealed as questionable, since the majority of walking trips do not originate from the home. The relationship between urban land-use patterns and walkability may therefore require some rethinking.

1. Introduction and aims

The promotion of active-transport (AT) walking is an important goal of both land-use and transportation planning, since walking is an environmentally–friendly alternative to motorized travel in urban areas, and an important form of healthy physical activity (Sallis et al., 2004). Walking research tends to reside in two bodies of literature (health/leisure versus transport/land-use), both with their own viewpoints, methods, and policy orientations. Both approaches to walking research have suffered from a lack of objective data on walking behavior, typically relying on recall questionnaires using subjective categories of walking frequencies and durations. In particular, little information is available on the geography of walking behavior: travel episode origins and destinations, routes, and lengths (durations and distances).

This paper addresses this gap in our knowledge. We report and assess aggregated AT walking behavior derived from the innovative STAR (Space–Time Activity Research) time-use and transport survey, which tracked respondents using a GPS-enabled (global positioning system) personal data device. Elsewhere, we used STAR data to investigate travel purposes, participant characteristics, and travel episode timing (season, day of week, time of day) (Spinney et al., 2012). Our focus in the current paper is on origins, destinations, durations, and distances. We are particularly interested to investigate the assumption, frequently made in the planning literature, that AT walking episodes normally originate or terminate at home. We also investigate in detail the major attractors (destinations) for purposeful walking, and gauge their attractive power (gravitational weights) and distance-decay functions.

2. Related theory and empirical research

Of the four domains of physical activity (i.e., leisure, active transportation, personal care, and work activities) (Armstrong and Bull, 2006; World Health Organization, 2002), walking is an important component of both the active transportation and leisure domains. Studies have shown that walking is the most common form of leisure-time physical activity in Canada (Gilmour, 2007), the US (Rafferty et al., 2002), and Europe (Pucher and Dijkstra, 2003), and leisure walking has been the focus of most walking studies. Health researchers and public health officials are attracted to the potential for enhancing healthy exercise thorough leisure

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walking (Trost et al., 2002; Williams et al., 2008), and to a lesser extent through active transport (Hamer and Chida, 2008; Kitchen et al., 2011; Merom et al., 2010; Shephard, 2008), but some researchers (Cervero and Duncan, 2003) caution that many aspects of the North American built environment "conspire against walking".

In the land-use planning literature, considerable research has focused on relationships between walking activity, health, and the built environment, typically using self-reported quantities of total walking, or of leisure walking. These studies inform and support policies aimed at increasing the mode share of walking, and hypothesize that walking behaviors are significantly affected by the "walkability" of neighborhoods focused on respondents' homes (typically employing a buffer radius of one kilometer). They make an implicit assumption, therefore, that walking largely or exclusively occurs within such neighborhood areas. Early conceptual and expository papers on this theme were provided by Atash (1994), Crane (2000), Frank and Engelke (2001), Handy et al. (2002), Moudon and Lee (2003), and Saelens et al. (2003). Many empirical studies have been conducted, and several meta-studies are now available (Ewing and Cervero, 2010; Gebel et al., 2007; Lee and Moudon, 2004; Renalds et al., 2010; Sallis, 2009; Saelens and Handy, 2008). A large proportion of the studies use walkability measures of residential density, street connectivity, and land-use mix derived from an early study by Boarnet and Sarmiento (1998), but incorporated into a single 'walkability index' by Frank et al. (2005). Though easy to use and understand, this index has varied in its details and sub-index weightings from study to study. In addition, the sub-indexes are inter-correlated, so that their effects are not simply additive, and their separate contributions are not reported. An alternative approach, taken by Lee and Moudon (2006), employs multiple regression to isolate the separate effects of a host of land-use and urban-form measures (and personal characteristics too). Their 'shotgun' approach is more statistically rigorous, but far less opaque, and difficult to replicate.

Many walkability studies have focused on measuring and predicting all walking, undifferentiated by purpose. Some studies, particularly those employing questionnaires derived from an IPAQ (International Physical Activity Questionnaire), differentiate between walking for leisure/recreation and walking for transport (AT), and a small number of studies have focused largely or exclusively on walking for transport. Of the latter, we should particularly note studies by Cerin et al. (2007), Duncan et al. (2010), Frank et al. (2006, 2007, 2008a), Kitchen et al. (2011), McGinn et al. (2007), and Yang and Diez-Roux (2012). Recently, several studies have examined the prevalence of walking to school, and its relationship to neighborhood walkability (Spinney and Millward, 2011a; Babey et al., 2009; Collins and Kearns, 2010; Merom et al., 2006; Mitra et al., 2010; Pont et al., 2009; Timperio et al., 2006).

Transport researchers have been concerned to identify the factors that affect mode choice and trip rates relating to active travel. Following important early studies by Frank and Pivo (1994) and Cervero and Kockelman (1997), several papers have examined walking mode choice and trip behavior in comparison to cycling and motorized modes (Cervero et al., 2009; Chen and McKnight, 2007; Kelly et al., 2011; Rodriguez and Joo, 2004; Schwanen and Mokhtarian, 2005; Walton and Sunseri, 2010). Newbold et al. (2005) examined walking trip-choice in relation to age cohorts, while Scheiner (2010) related the choice to age cohorts, sex, city size, availability of car, and trip distance. Using several German surveys, he showed that walking is the dominant trip mode at distances below one kilometer, and still very important in the 1–2 km band.

A major problem with walking studies in general, but particularly those focusing on neighborhood walkability, has been the quality and reliability of data on walking behaviors. Most walkability studies have relied on subjective recall questionnaires, typically derived from IPAQ. They measure amount of walking activity by a small number of subjective categories, rather than by exact number or length of walking episodes, and they are influenced by both recall bias and social-desirability bias (CFLRI, 2009; Klesges et al., 2003; LaMonte et al., 2003; Rizzo et al., 2007; Van der Ploeg et al., 2010). As an example, Cerin et al. (2007) related both objective and perceived measures of neighborhood walkability to self-reported estimates of weekly duration of walking for transport, and self-reported monthly frequency of walking to specific destinations. A few walking studies have employed time diaries, which are more accurate than recall questionnaires (e.g. Forsyth et al., 2007; Frank et al., 2008b, 2010), and one research team used a time-diary in combination with accelerometers to measure distances (Forsyth et al., 2007, 2008). All walkability studies, however, focus on correlating urban form measures with a single measure of respondent walking activity (often a category rather than scale measure), and do not attempt to analyze the varying characteristics of the walking episodes themselves.

Time diary data have long been recognized as an important method for measuring and studying human behavior (Ås, 1978; Gershuny, 2000; Meier, 1959; Robinson and Godbey, 1999). Several recent studies have employed national time-use surveys to investigate walking behaviors. Studies by Tudor-Locke et al. (2005) for Australia and for the United States (Tudor-Locke et al., 2007) revealed interesting variations between walking for leisure and walking for transport. These findings are complemented by data from Canadian national health surveys on the self-reported prevalence of walking for exercise (Bryan and Katzmarzyk, 2009). Adams (2010) uses the United Kingdom national Time Use Survey to focus specifically on active-transport (AT) walking/bicycling, and to model the characteristics of those participating in AT. In the United States, the 2009 National Household Travel Survey, based on a 24-h travel diary, has yielded useful data on distances and durations of walking trips, employing seven broad purpose categories (Yang and Diez-Roux, 2012).

In a recent study the authors employed GPS-verified time-diary data from the Halifax STAR project to provide a thorough comparison of AT-walking versus leisure walking (Spinney et al., 2012). The results indicate substantial and significant differences between the two types of walking, related to participants, location categories, and timing (season, day of week, and time of day). Compared to walking for recreation, walking for transport has higher participation rates and more occurrences, and travel episodes are more likely to originate and terminate outside of the home. Similar to findings for Australia (Tudor-Locke et al., 2005), we found that walking for transport contributes less to total physical activity than walking for recreation, because the latter exhibits much longer durations, both per travel episode and per participant.

The current study builds on this earlier work by providing a more detailed examination of AT-walking related to origins and destinations, highlighting the importance of some specific service and amenity destinations. A notable "first" is the use of GPS data to measure accurately the origin and destination of walking episodes, and thereby calculate travel episode distances accurately, thus enabling us to study both time-decay and distance-decay gradients.

3. Data and methods

3.1. The STAR survey

This study employs time-diary and questionnaire data, and GPS geo-coordinate data, from the Space–Time Activity Research

(STAR) survey conducted in Halifax, Canada. This was the world's first large-scale application of a GPS-assisted prompted recall survey, and the "largest GPS sample within the context of a household travel survey project undertaken to date" (Bricka, 2008, p. 3). Detailed descriptions of the survey design (Spinney and Millward, 2011b; TURP, 2008a), and a socio-demographic profile of respondent characteristics (Millward and Spinney, 2011), are reported elsewhere. A brief summary of the survey design follows. The target population for this randomly-selected sample was private dwellings in Halifax Regional Municipality (HRM), a county-sized metropolitan area along the east coast of Nova Scotia, Canada. The survey was conducted between April 2007 and May 2008. The primary sampling unit was the household, while the secondary sampling unit was a randomly selected individual member of the household, over the age of 15, who acted as the primary respondent, and completed a computer-assisted telephone interview (CATI) questionnaire, carried a cellular-assisted GPS device (Hewlett Packard iPAQ hw6955) for a 48-h reporting period, maintained a daily "activity log" during that period, and completed a two-day time-diary survey the day after the two-day reporting period had ended. The respondents' descriptions of their activities were aided by the GPS data for prompting and validation purposes, and later categorized into 188 different activity codes that, for validation and comparison purposes, were based on Statistics Canada's 2005 General Social Survey on Time Use (TURP, 2008b).

3.2. Measures of walking

The STAR survey, like other time-dairy surveys, captured the complete daily record of consecutive activity *episodes* or *events* (see Harvey, 1990), which include the activity being performed (e.g., eat, sleep, work), the start and end time of each event, and concurrent contextual information, such as the location of the event (e.g., home, work, outdoors). The STAR survey provides "travel mode" (e.g., car as driver, bus, walking) information using the location of each event, and employs the activity code of each event to capture the "travel purpose" (e.g., code 90 is used for "travel to/from work", while code 390 represents travel for "shopping and services"). We used activity information to identify all walking for recreation events (code 821), but the identification of walking for transport events required the use of information about both the main activity and the location of each episode. That is, walking for transport includes all travel activities whose location indicates walking as the travel mode. On the other hand, walking for recreation includes recreational walking, hiking, and jogging activities, and while most of the location codes indicate walking, this activity may occur at any location, including parks, trails, and even shopping malls, as examples.

Time-diary data collection was aided by GPS data to enhance the accuracy of start times and end times of each walking episode, whether for transport or recreation, with the data used to compute the time duration of each episode. TransCAD®, a geographic information system (GIS) for solving transportation problems, was used to compute a network-based shortest-path (i.e. Manhattan) distance between the GPS-derived origin and destination of each walking episode. Walkable roads and trails comprised the "walking" network used to complete this task.[1] Episode speed was computed by dividing network distance by time duration. While most AT walks in the STAR data are defined as single-episode trips, from one stationary location to another, the coding protocol and GPS software used a one-min temporal resolution, which precluded direct measurement of travel distances and speeds for many sequential travel location (STL) travel episodes (multi-modal travel episode chains). As an example, a respondent might be driven to work by his/her spouse, but walk the final few blocks. If the respondent was not stationary at the drop-off point for more than 1 min, the location of the drop-off point was often not captured by the GPS or the interviewer. Most of these intermediate locations would be bus stops and parking lots, and in most travel surveys these data would not exist at all. Of the 3810 AT-walking travel episodes in the STAR dataset, 883 (or 23.2%) were identified as STL travel episodes, and were excluded from the analysis. In addition to STL travel episodes, there are also a number of "round-trip episodes" that were identified, in which the origin and destination have the same locational co-ordinates. Again, distances and speeds could not be calculated for these episodes, and they were excluded. Most such travel episodes were recreational walks, but 206 AT round-trip episodes were also excluded. A small number of "apparent" AT round-trip episodes show in the tables in this paper: GPS data confirmed these to be valid travel episodes, with different origin and destination co-ordinates (e.g. two buildings on a college campus), so that distances and speeds could be calculated accurately using TransCAD®.

There were also some travel distances, brought to light by excessive travel speeds, that resulted from inaccuracies in the 'places and locations' (PAL) database used to geo-code origins and destinations when GPS data were not available to the interviewer. The PAL database contains geographic coordinates and standard industrial classification (SIC) code information for more than 12,000 non-residential "locations," but only 91% of these are geo-coded to the street/civic address. Distance and speed computations for travel episodes to/from the remaining 9% are inherently liable to error, but we detected the most egregious errors from excessively slow and fast travel speeds. Only travel episodes with speeds in the following ranges were allowed: walking (AT and recreational) = 2–10 km/h, bicycle = 3–30 km/h, car = 3–110 km/h, bus = 3–110 km/h.

3.3. Statistical analysis

Statistical analysis, performed using the Statistical Package for the Social Sciences (SPSS) version 15.0, was used to characterize aggregate categories of walking for transport (purposes and destinations), and to investigate the significance of differences between such categories. Summary statistics, including measures of both central tendency and dispersion, are used to characterize AT walking, while mean and median values for other travel modes are used to provide reference. Cross-tabulations of origins and destinations are used to illustrate the percentage distribution of travel episodes, while mean distances and durations are also illustrated using origin–destination matrices. The percentage distributions of AT walking trips are examined along with mean durations and distances for each travel purpose, for destinations based on SIC codes, and for destination localities (major employment nodes). We also employed simple linear regression to derive time-decay and distance-decay gradients related to key destinations.

4. Results and discussion

4.1. Walking durations

As Table 1 shows, AT walking tends to be somewhat faster than recreational walking, as befits its more purposeful nature. AT walks, however, tend to be shorter in both time and duration, with a median time duration of only six minutes. This is half the duration of recreational walks, or of travel episodes by bicycle and car, and one third the duration of bus travel episodes.

[1] The network data were obtained from DMTI™ Spatial Inc.'s CanMap® Route Logistics GIS data product, Version 2008.3.

Table 1
Summary statistics on AT-walking trips and trips by other travel modes (single-episode trips only).

Trip type and statistic	Count	Duration (min)	Distance (km)	Speed (km/h)
AT walks				
Mean	1790	9.0	0.67	4.8
Median		6.0	0.48	4.5
25th percentile		3.0	0.23	3.4
75th percentile		12.0	0.86	5.9
Recreational walks (non round-trip)				
Mean	97	17.3	1.02	4.3
Median		12.0	0.90	4.0
Bicycle				
Mean	147	18.3	3.47	11.2
Median		10.0	2.04	11.1
Car				
Mean	20,680	13.7	7.97	33.3
Median		10.0	3.86	25.3
Bus				
Mean	158	26.9	6.26	16.2
Median		20.0	4.96	15.0

As typically assumed in the literature, home is both the most common origin for AT walks, and the most common destination (Table 2). Note that travel episodes from home are more frequent than travel episodes to home. This is because we are tabulating only single-leg (non-STL) travel episodes. People are more likely to take single-leg travel episodes to rather than from work, whereas STL travel episodes are fairly common between work and home.

Somewhat surprisingly, our data reveal that the majority of AT walk travel episodes have origins or destinations other than home or work, mostly to "other places" such as retail establishments and offices. Indeed, the most common travel episode category is 'other place to other place'. Owing to our detailed GPS validation procedures, these results differ from those reported by traditional travel surveys, which fail to recognize the extent and variety of AT walking. Our results show clearly that AT is far more than simply an alternative form of workplace commuting; it can be used and enjoyed for many purposes by students, retirees, and other non-workforce individuals. It should be noted that school-age children were greatly under-represented in our data, since primary respondents had to be 15 years or older; most "school" travel episodes were by college students.

Nevertheless, commuting travel episodes are important, because of their length, both in duration (Table 3) and distance (Table 4). This situation reflects the fact that major employment areas (downtown, industrial parks, business parks) tend to be highly separated from residential areas. Of frequently occurring travel episode categories (those with 0.5% or more of travel episodes), travel episodes to/from home and other places are also much longer than average, perhaps reflecting the lack of destination opportunities, particularly for shopping, in many residential neighborhoods, as bemoaned in the planning literature.

For frequent categories, shorter-than-average episodes are evident for travel to/from outdoors and workplace. Such travel episodes often occur at lunch time, or on shorter work breaks, and include smoking breaks outdoors.

4.2. Purposes and destinations

Table 5 presents information on the purposes for AT walking episodes, using 20 purpose categories harmonized with those employed in Statistics Canada's national time-use surveys. Travel for goods and services (shopping) is the most common travel purpose, both for all modes (33.0%) and for AT walking (34.4%). Travel to/from work is the second-most frequent, with 16.8% for all modes and 18.5% for AT walking. These two travel purposes account for 52.9% of all AT-walking travel episodes.

Although only 8.3% of all travel episodes are by AT walking, certain purpose categories favor this mode. Most notable is "media and communications," with 31.7% of travel episodes by AT walking; these are mostly travel from the respondent's property to pick up the mail, often at community mailboxes. AT walking also shows high modal splits for education, restaurant meals, 'other personal activities' (e.g. eating not at a restaurant, visit to a public washroom, or no explanation given), 'other socializing' (i.e. non-residential social entertainment such as visiting a bar), and sports and entertainment. Since a large proportion of all travel episodes are for restaurant meals, this purpose category ranks third in importance for AT walks, at 10.2% of travel episodes. Travel for in-home socializing ranks next, at 5.5% of AT travel episodes.

As already mentioned, travel episodes to/from work are somewhat lengthier than average in both duration and distance. Travel for goods and services and for restaurant meals is a little shorter than average, while travel for in-home socializing is shorter still. Exceptionally long walking travel episodes are evident for 'entertainment or other active leisure' (e.g. walked to the river to fish, walked along the waterfront to watch the fireworks), crafts and hobbies, religious services, and sports and entertainment (e.g.

Table 2
Percentage of 1790 AT walking trips, by origin and destination categories (single-episode trips only).

Origins	Destinations						
	Home	Workplace	Other's home	School	Outdoors	Other place	Total
Home	0.0	3.5	4.2	0.1	6.1	10.9	25.0
Workplace	2.8	0.4	0.0	0.0	2.7	13.3	19.3
Other's home	4.1	0.2	0.4	0.1	0.3	0.9	6.0
School	0.2	0.0	0.1	0.3	0.2	0.6	1.3
Outdoors	2.1	1.5	0.2	0.1	0.2	1.6	5.6
Other place	11.1	11.5	0.8	0.7	2.5	16.3	42.8
Total	20.5	17.0	5.7	1.2	12.0	43.6	100.0

Table 3
Mean AT walking-trip durations (min), by origin and destination categories (single-episode trips only).

Origins	Destinations						
	Home	Workplace	Other's home	School	Outdoors	Other place	Total
Home	–	14.6	7.4	15.0	7.4	13.5	11.1
Workplace	14.8	8.5	–	–	6.6	7.8	8.7
Other's home	6.3	27.3	8.4	18.0	5.8	9.7	7.6
School	19.8	–	21.0	3.8	10.3	7.3	9.7
Outdoors	6.9	5.5	5.0	5.0	3.3	6.7	6.3
Other place	12.9	6.4	8.5	7.3	6.9	6.9	8.3
Total	11.2	8.3	7.7	7.6	7.0	8.9	9.0

Table 4
Mean AT walking-trip distances (km), by origin and destination categories (single-episode trips only).

Origins	Destinations						
	Home	Workplace	Other's home	School	Outdoors	Other place	Total
Home	–	1.19	0.59	1.15	0.54	0.95	0.82
Workplace	1.15	0.61	–	–	0.48	0.59	0.66
Other's home	0.47	2.61	0.79	1.26	0.65	0.61	0.58
School	1.65	–	1.27	0.42	0.51	0.64	0.78
Outdoors	0.58	0.44	0.36	0.39	0.28	0.50	0.50
Other place	0.96	0.50	0.63	0.58	0.44	0.49	0.62
Total	0.85	0.66	0.60	0.62	0.51	0.64	0.67

Table 5
AT walking-trip characteristics, by travel purpose categories (single-episode trips only).

Travel purpose	% Of all trips (all modes)	AT walk-trips as% of total	% of AT walking trips	Mean walk duration (min)	Mean walk distance (km)
During Work	5.2	6.4	4.0	10.4	0.83
To or from work	16.8	9.2	18.5	10.8	0.84
For domestic work	2.0	10.1	2.5	7.8	0.62
For household child	6.4	3.8	3.0	8.0	0.59
For household adults	5.5	0.6	0.4	10.9	0.94
For goods and services	33.0	8.7	34.4	8.5	0.62
To restaurant meals	4.6	18.6	10.2	7.8	0.55
For other personal activities	0.9	17.3	1.8	8.2	0.62
For education	1.1	18.9	2.4	9.7	0.77
For civic & voluntary activity	3.3	6.8	2.7	6.3	0.46
For religious services	1.8	3.5	0.8	14.9	1.12
For transportation assistance	4.1	3.8	1.9	5.4	0.45
To sports & entertainment	2.0	11.1	2.7	12.5	0.92
For in-home socializing	5.2	8.9	5.5	6.9	0.53
For other socializing	1.9	12.9	3.0	9.8	0.74
For physically active leisure	3.9	7.8	3.7	9.8	0.69
For coaching	0.1	0.0	0.0	–	–
For crafts and hobbies	0.2	2.9	0.1	16.0	1.03
For entertaining or other active leisure	1.2	2.3	0.3	24.5	1.88
For media or communication	0.6	31.7	2.2	5.3	0.40
Total	100.0	8.3	100.0	9.0	0.67

walked to baseball game, walked to the movie theatre). Exceptionally short travel episodes are recorded for media or communications (to mailbox), transportation assistance (i.e. unpaid help with transportation given to friends, neighbors or relatives who do not live in the respondent's household), civic and voluntary activity, and in-home socializing (often involving visits with friends and neighbors).

Table 6 presents data for specific walking destinations, in order of their frequency. As already noted, home and workplace take the largest share of travel episodes. Somewhat surprisingly, bus stops rank third as a destination. This is an artefact of the STAR locational coding, which recorded waiting at bus stops for more than 1 min as stationary episode locations, and thus valid end-points for single-episode trips. In reality, these trips would continue by bus, as part of a multi-modal trip. The same coding issue applies to many trips destined to parking lots.

Most of the major destinations in Table 6 relate to commercial activity, in stores or offices. Particularly important are restaurants and bars, grocery stores, shopping centers, banks, and other services. Of lesser importance are fast foods, drug stores, private recreation facilities, sports retail, hotel/motel, department stores, and variety stores. Walking is a particularly popular travel mode for hotels/motels (14% of trips), and also for shopping centers/malls, restaurants/bars, and banks. It is not popular for department stores, private recreation (ironically), other services, or grocery stores. Mean distances to commercial destinations are mostly around 0.6 km, but those to banks, shopping centers, and hotels/motels are 0.75 or higher, while those to department stores, sports retail, and fast food are below 0.5.

Several non-commercial destinations deserve mention. The most important is 'someone else's home', at 5.7% of AT walking trips, followed by 'outdoors away from home', at 2.7%. Also

Table 6
AT walking trips, by specific destinations (single-episode trips only).

SIC-based destinations	% of AT walking trips (n = 1790)	AT walking trips as% of all trips	Mean walk duration (min)	Mean distance (km)
Total	100.0	8.3	9.0	0.67
Respondent's home	20.8	6.0	11.1	0.84
Workplace	17.0	17.2	8.3	0.66
Bus stop or ferry terminal	9.1	44.3	7.0	0.51
Restaurant or bar	7.8	10.7	7.7	0.52
Someone else's home	5.7	4.8	7.7	0.60
Grocery store	5.2	6.7	8.4	0.63
Other retail	3.7	7.4	8.1	0.59
Shopping center or mall	3.3	12.4	10.6	0.75
Outdoors away from home	2.7	20.2	7.5	0.56
Bank	2.7	10.7	10.6	0.78
School	2.4	8.4	10.4	0.76
Other services	2.3	6.3	8.6	0.66
College or university	1.6	19.6	7.9	0.66
Fast food	1.5	7.1	7.1	0.45
Drug store	1.5	9.9	7.4	0.51
Government Services	1.3	9.2	10.0	0.78
Park or Beach	1.1	11.2	12.0	0.80
Place of worship	0.9	5.5	12.6	0.91
Private Recreation Facility	0.9	6.0	7.8	0.67
Library	0.8	16.3	10.9	0.74
Retail Sports and Apparel	0.8	9.5	4.9	0.37
Motel or Hotel	0.7	14.0	10.5	0.75
Hospital	0.7	7.1	10.3	0.84
Department Store	0.6	2.3	5.2	0.36
Variety Store	0.6	6.8	8.1	0.50
Parking Lot or Structure	0.6	20.0	3.8	0.32
Gas Station	0.5	1.8	3.9	0.26
Barber or Salon	0.5	9.5	10.2	0.72
All Other	2.8	3.3	10.7	0.75

important are schools and college/university. Trips to schools have a particularly long mean distance, so only 8.4% of school trips use the walking mode. By comparison, almost 20% of trips to college/university employ walking.

Most non-home walking destinations are workplaces, shops, or offices. These types of destinations tend to cluster in the downtown core, or in other employment nodes such as suburban business parks. From detailed land-use mapping, we delineated the

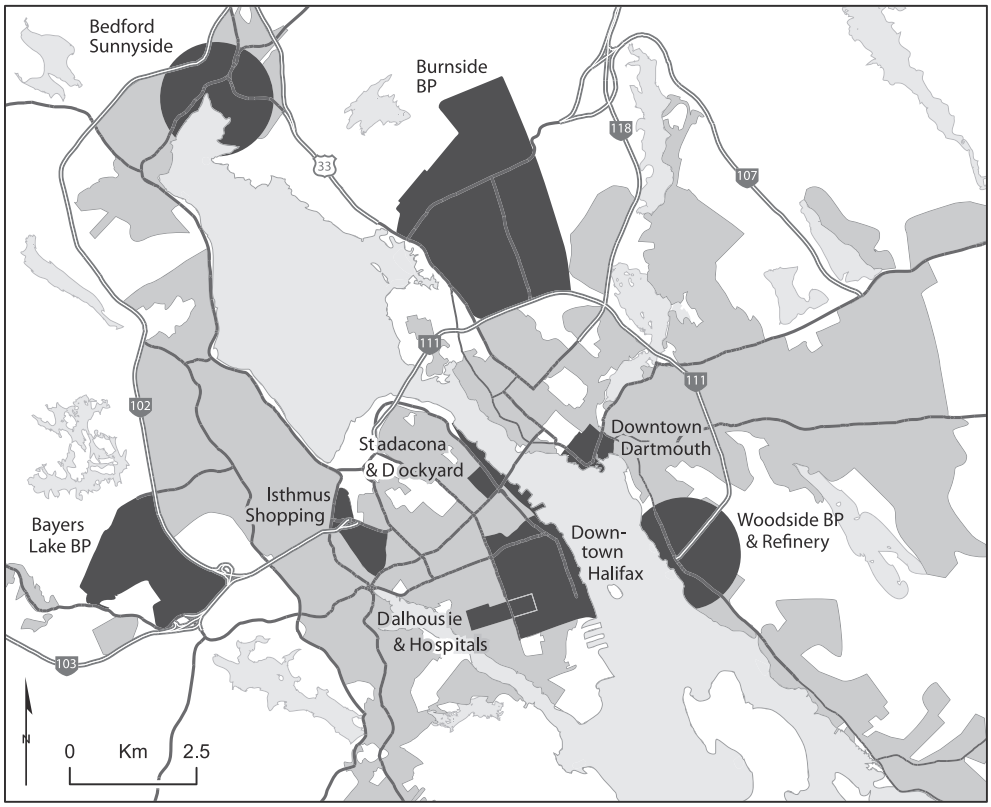

Fig. 1. Location of major employment nodes within the Halifax urban area.

Table 7
AT walking trips, to destinations in major employment nodes (single-episode trips only, to non-home destinations).

Major employment node	% Of all non-home AT walking trips (n = 1423)	AT walking as% of all non-home trips to this node	Mean walk duration (min)	Mean distance (km)
Downtown Halifax	41.5	38.0	8.0	0.59
Downtown Dartmouth	7.0	13.2	9.0	0.64
Halifax isthmus shopping centers	2.5	8.9	10.7	0.83
Bedford Sunnyside	2.3	7.2	9.1	0.58
University avenue (Hospitals & Dalhousie U)	2.0	26.2	7.1	0.62
Stadacona base and dockyard (military)	1.5	16.8	8.8	0.67
Burnside business park	1.4	3.4	9.4	0.87
Bayers lake business park	1.3	3.2	3.1	0.31
Woodside BP and imperial oil refinery	0.8	7.0	10.8	0.98

10 official business parks, the Halifax and Dartmouth downtown districts (either side of Halifax Harbor), and six other employment nodes (three in the inner city and three in the suburbs). Locations of the major nodes are shown in Fig. 1. As Table 7 shows, downtown Halifax alone takes 42% of AT walks with non-home destinations, and downtown Dartmouth a further 7%. Following these are several well-established shopping areas in the inner suburbs, an inner-city hospital/university district, and an inner-city military district. AT walking trips take a large share of all trips to the downtown and inner-city nodes, and an impressive 38% of trips to downtown Halifax.

The three largest suburban business parks are listed in Table 7, but they generate only a small share of AT walking episodes. Burnside is a particularly large employment node, with half as many jobs as downtown Halifax, but its low-density auto/truck orientation is clearly apparent, in that only 3.4% of trips are in the AT walking mode, compared to 38% downtown. Bayers Lake Business Park is primarily a retail power center, where most walking trips are between adjacent big-box retail outlets, as can be inferred from the short mean duration and distance.

4.3. Distance-decay gradients

As shown earlier, AT walking episodes tend to be short in both duration and distance. This suggests a strong "friction of distance" (Ellegard and Vilhelmson, 2004) effect, in which the propensity to walk declines exponentially with distance and/or time (Fotheringham, 1981; Williams, 1977). If the distance-decline effects for various destination types are strong and highly predictable, then we have important evidence that can be subsequently incorporated into empirically-derived predictive models of walking behavior.

We constructed distance-decay and time-decay gradients for all AT walking episodes combined, and for episodes related to each of the major destinations (those in Table 6 with over 2% of the total). We graphed the frequency of walks against distance bands of 0.2 km (also used by Scheiner, 2010) and duration bands of two minutes, and to make these various gradients comparable, we converted the raw frequencies in each distance or time band into percentages. Fig. 2 shows the results for walking distances, which are the most useful for the purpose of predictive modeling. However, the gradients for walking durations are very similar. All of the distance-decline gradients show the expected shape (negative exponential decline), and they are also remarkably similar in their peak values and gradients.

For most destinations, the peak value is in the 0.2–0.4 km range, which simply reflects land-use separation, and the fact that destinations seldom occur in the immediate vicinity of origins. Regarding gradients, 42% of all trips are shorter than 0.4 km, 72% shorter than 0.8 km, and 85% shorter than 1.2 km. These values are remarkably similar to those graphed by Yang and Diez-Roux (2012) from US travel survey data. Walks to bus-stops have a higher peak and steeper gradient, such that 52% of trips are shorter than 0.4 km and only 7% exceed 1.2 km. These findings vindicate the frequent use of distance thresholds of 400 or 500 m in the planning of bus routes and bus-stop locations. In contrast, walks to respondents' homes have a lower peak and gradient, such that only 34% are shorter than 0.4 km, and fully 25% are longer than 1.2 km. There may be several reasons for this, but in part it reflects the high gravitational "pull" of home. Banks also seem to have high pull, such that people are willing to walk further to them than to grocery stores or restaurants. They also need to do so, of course, since banks are fewer and further apart.

Negative exponential curves can be modeled through linear regression, by taking logarithmic values of the dependent variable. Here, the exponential equation is

$$\%\text{Trips} = a b^{-\text{Distance}}$$

which transforms to

$$\log(\%\text{Trips}) = \log a - \log b(\text{Distance}).$$

Table 8 provides the resulting correlation and regression coefficients, for both distances and time durations. Nearly all the correlations are very high, and significant at the 0.01 level, with those for distance being somewhat higher. Destinations with higher peak values ($\log a$) tend to have steeper gradients ($\log b$), and vice versa. However, the distance and time gradients do not always agree: restaurants and grocery stores have steep distance gradients, but shallow time gradients. Gradients to most of the major destinations tend to be shallower than those for all walks combined, reflecting a stronger gravitational pull.

5. Summary and conclusions

This paper fills a gap in our knowledge of active-transport (AT) walking, by presenting detailed aspects of walking behavior for a medium-sized North American city, as reported in GPS-verified, day-after recall time diaries. Such data have not previously been available, and allow empirical validation of various assumptions and estimates reported previously in land planning and health journals. Our analysis focused on travel episodes rather than on participant characteristics. Unfortunately, distance and speed could not be calculated for sequential travel episode (STL) trips and round trips, so that the analysis is restricted to single-mode non-round trips. We analyzed the frequency, time duration, and distance of such walking travel episodes, as they relate to travel origins, purposes, and destinations. The intent has been to determine the major types of destinations for purposeful walking, to gauge their attractive power, and to assess distance ranges within which most walks occurred (in effect, the extent of walking catchment areas).

An important finding is that most AT walking episodes have origins and destinations other than home or work. However, home is the most common origin and destination, and workplace is the second most common. Shopping travel is the most common travel purpose, and travel to/from work is the second most common purpose. Major commercial destinations are restaurants/bars, grocery stores, shopping centers, and banks. Important non-commercial destinations are bus stops (ranked third overall), 'someone else's

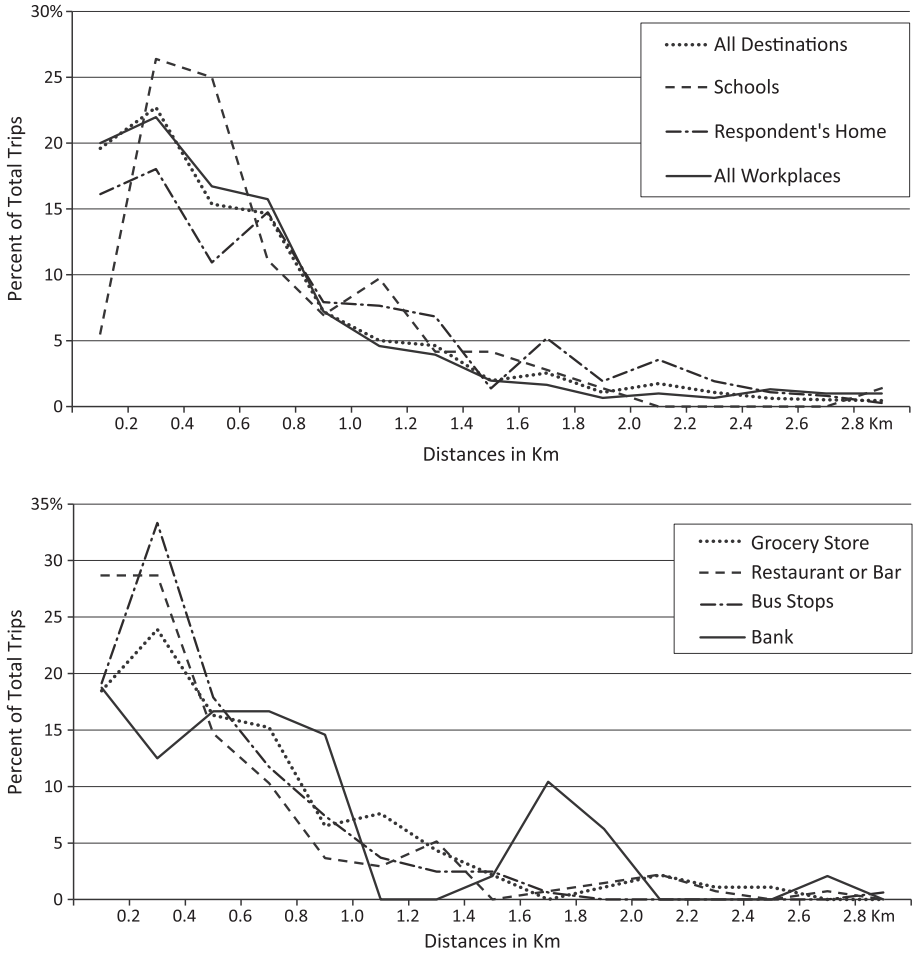

Fig. 2. Distance-decay gradients for major AT-walking destinations.

Table 8
Linear regressions: percentage of AT walking trips to destination (Y) against distance/duration (X).[a]

Major destinations	X = distance (km)			X = time duration (min)		
	r Coeff.[b]	Peak log a	Slope log b	r Coeff.[c]	Peak log a	Slope log b
All destinations	.99	1.456	−.643	.94	1.282	−.048
Respondent's home	.95	1.359	−.519	.91	1.193	−.037
All workplaces	.92	1.328	−.543	.88	1.111	−.039
School	.85	1.248	−.401	.57	1.014	−.020
Bus stop or ferry terminal	.91	1.351	−.569	.88	1.277	−.052
Restaurant or bar	.93	1.427	−.652	.81	1.035	−.032
Grocery store	.96	1.458	−.614	.80	1.078	−.028
Bank	.81	1.343	−.355	.39	0.987	−.010

[a] *Note*: $Y = a\ b^{-X}$ and $\log Y = \log a - \log b(X)$.
[b] All significant at $\alpha = .01$.
[c] All significant at $\alpha = .01$, except School at .04 and Bank at .21.

home', 'outdoors away from home', school, and college/university. All major destinations show strong and highly predictable distance-decay and time-decay effects, which can be modeled as negative-exponential equations. These distance and time gradients demonstrate that most walks are quite short (typically less than 600 m) and very few walks exceed 1200 m.

Given the desire to accommodate walkers of varying ages and abilities when planning the location of facilities such as bus stops, the oft-used walking range of 400 m (Atash, 1994) is partially vindicated. Also, the assumption frequently employed in the walkability literature (and specifically in the widely-used "walkability index"), that one should restrict the 'neighborhood of opportunity' to walking destinations within 1000 m of the home, is seen to be well justified. However, a planning policy focus on the walker's home neighborhood is revealed as questionable, since the majority of walking trips do not originate from the home. Our results therefore suggest that some re-thinking may be required regarding the relationship between urban land-use patterns and walkability. Planners concerned with increasing AT walking opportunities and walking's mode share should recognize the importance of non-home trips, and encourage opportunities for them. This paper demonstrates that we are now in a position to construct empirically-derived predictive models of walking behavior. Such models will be more conceptually sound than existing predictive tools such as the walkability index, and can be tailored to focus on specific destinations or destination-categories, or to predict total AT-walking activity around a home, workplace, or other origin location.

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