

# What is the relationship between food shopping and daily mobility? A relational approach to analysis of food access

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**Abstract** Recent research on food access has increasingly focused on how individuals' daily mobility, much of it based on activity spaces created from GPS data. In this paper, we expand this research through an analysis of a large transit survey ( $n = 21,298$  households) from Minneapolis/St. Paul, Minnesota. We do this using relational approach focused on the topological connections found in household travel patterns rather than measures of exposure based on geographic distance. Our exploratory data analysis analyzes both grocery shopping and eating out across the metropolitan area, focusing on the position of utilized food sources relative to home and work locations, utilized modes of transit, and other daily activities often combined with food shopping. Households often used food sources located outside their residential neighborhoods, usually moving toward the central city to do so. Eating out occurred farther from home than grocery shopping, though in many cases close to work. Automobile use was most common for grocery shopping trips, but less so in the lowest income households and in the central city. Our findings show that a relational approach can identify distinctive patterns in everyday food provisioning by

emphasizing the connections between food shopping and other everyday household activities.

**Keywords** Food access · Mobility · Transit · Exploratory data analysis

## Introduction

Over the last decade, research on food access has often employed a spatial analytical approach, using GIS software to calculate the proximity of various food sources (e.g., supermarkets, fast food) to the place of residence for vulnerable populations. The USDA's Food Access Research Atlas, for example, measures average distance to supermarkets at the census tract level, combining it with census data on poverty to identify what it terms low income, low access (LILA) areas (USDA Economic Research Service 2014). In many cases, this research does identify low income areas underserved by large food retailers (Raja et al. 2008; Zenk et al. 2005). However, the relation between store accessibility and dietary outcomes has been "remarkably inconsistent" (Caspi et al. 2012, p. 1175). Research sometimes identifies associations between certain store types, such as fast food retail, and dietary outcomes such as consumption of fresh produce or rates of obesity (Forsyth et al. 2012; Inagami et al. 2009). Other research has found a link between store environment and residents' shopping habits

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(Cannuscio et al. 2013). However, in many cases researchers have found little evidence of a broad tie between food retail environment and food availability or consumption (Black et al. 2014; Cummins et al. 2014; Martin et al. 2014).

Much of this research analyzes food accessibility based on administrative areal units. The USDA, for example, identifies food deserts at the census tract level. This practice risks an ecological fallacy. Households may be differentially affected by food store proximity (or lack thereof) based on a wide range of factors besides household income: access to a vehicle, transit networks, culturally specific foodways, broader social networks, and already existing daily mobility (Glanz et al. 2005). Of these, mobility has received the most research attention in recent years, with several studies finding that stores used for food shopping can be two to three times as far from home as the closest supermarket (USDA Economic Research Service 2009, p. 63; Ver Ploeg et al. 2015). Clifton (2004) found that many of his participants' food trips were to stores outside the residential neighborhood. However, he notes that "the level of mobility required to reach these mainstream retailers comes with costs, including money, time, and missed opportunities" (p. 410). Ledoux and Vojnovic (2012) found that many Detroit residents bought food at suburban stores, and Zenk et al. (2011) found that when daily activity was tracked using GPS, residential environment was a "poor proxy" (p. 1155) for daily mobility and exposure to food retailers.

The results of these studies support calls for research on food access that incorporates individuals' daily mobility and spatiotemporal changes in the food environment (Kwan 2012; Saarloos et al. 2009; Widener and Shannon 2014). Chen and Kwan (2015) suggest real time shopping patterns and the temporality of the food system as priorities for work on food accessibility. Studies have engaged with the former through surveys and interviews measuring how often participants self-report shopping at stores outside their residential neighborhoods (Clifton 2004; Vojnovic et al. 2012). Other studies have used GPS data to create activity spaces, most often bounded polygons including all points visited by individuals throughout a set study period. Christian (2012) conducted a similar study of 121 residents in Lexington, Kentucky, finding that exposure to food retail measured through individuals' activity space was associated with dietary outcomes. Data on commuting patterns also provide insight on

daily mobility. Widener et al. (2013) created a measure of food exposure based on commuting patterns in the Cincinnati area, finding that it increased the number of available food sources and thus food accessibility for low-income households. Horner and Wood (2014) develop a probability based model they term the time geographic density estimation, calculating exposure to food retailers based on individuals' existing pathways and time budgets. Kestens et al. (2010), like the research described in this article, made use of a large travel survey to construct activity spaces to measure food store exposure.

The inclusion of daily mobility in analysis of food environments is a substantial improvement over earlier research. Yet it measures only *potential* exposure within a given activity space or daily path, while usually remaining uninformed regarding the ways *actual* food provisioning is tied to individuals' daily activity. By focusing on the topological relationships between places formed through daily practice, our research situates food shopping within both the urban landscape and other daily activities through an analysis of a large transit survey in Minneapolis/St. Paul. We ameliorate the risk of ecological fallacy found in prior work on the food environment through the use of households as our unit of analysis, examining the tours—sets of trips centered around home or work—that they engage in throughout the day. This makes it possible to identify differences within the same neighborhood environment that may be associated with income, transit accessibility, gender, age, or household size. Our analysis focuses on three main areas: how food shopping locations are related to both home locations and/or the point of origin for a tour, the means of transit used for food shopping, and the relationship between food shopping and other stops within a tour.

### A relational approach to food accessibility

This paper uses a relational approach to food access that draws significantly from a much cited piece by Cummins et al. (2007) and related previous work on relational space within geography (Massey 2005; Smith 2008). Cummins et al. contrast the "conventional view" of neighborhood effects on health—focused on absolute distances and static, immobile objects—with one more focused on mobility and relational connections. While GIS based research on food environments

has increasingly incorporated daily mobility, the design of most GIS software has resulted in analysis based on absolute measures of distance on conventional projections of the earth's surface. Cummins et al. advocate a topological view, one that “seeks to elaborate and extend traditional notions of proximity and distance as defining the separation of people and places” (p. 1827). Rather than considering only physical distance, a relational perspective also addresses the “socio-relational distance” between objects, which may not closely correlate with measures of physical distance. Individuals, for example, may develop strong connections to a particular grocery store or neighborhood that persist even when their place of residence changes. They may choose to cluster activities together in a single commercial district as a way to minimize the time costs of daily errands, or they may prioritize shopping at stores or in neighborhoods reflective of their classed and cultural identity. Thus, while particular food sources may not be geographically proximate to individuals as they move through the day, they may be close in a relational sense.

Our approach also has resonance with work based in the new mobilities paradigm (Conradson and Latham 2005; Cresswell 2010; Sheller and Urry 2006). This work has also prioritized conceptualizing individuals as essentially mobile, rather than locating them at a static point such as a place of residence. It does so to better understand the “life-worlds of these mobile individuals and the activities which constitute them” (Conradson and Latham 2005, pp. 228–229). Latham's (2003) study of changing patterns of use on one New Zealand commercial corridor offers one example. Using diaries, interviews, and photographs, Latham traces how changes to bars along the road reflected and reinforced increasingly cosmopolitan attitudes among the neighborhood's residents. Other studies of daily mobility among low-income populations have shown how reliance on public transit and the spatial mismatches between social service offices, childcare sites, and workplaces add to time and economic costs and complicate the lives of socially marginal populations (McQuoid and Dijst 2012; Rogalsky 2010).

Our research draws on this relational view of everyday mobility, focusing on its topology to understand how food shopping is embedded within larger rhythms of urban life. Instead of focusing on measures of absolute exposure—created through buffering GPS tracks or creating bounded polygons of activity space—

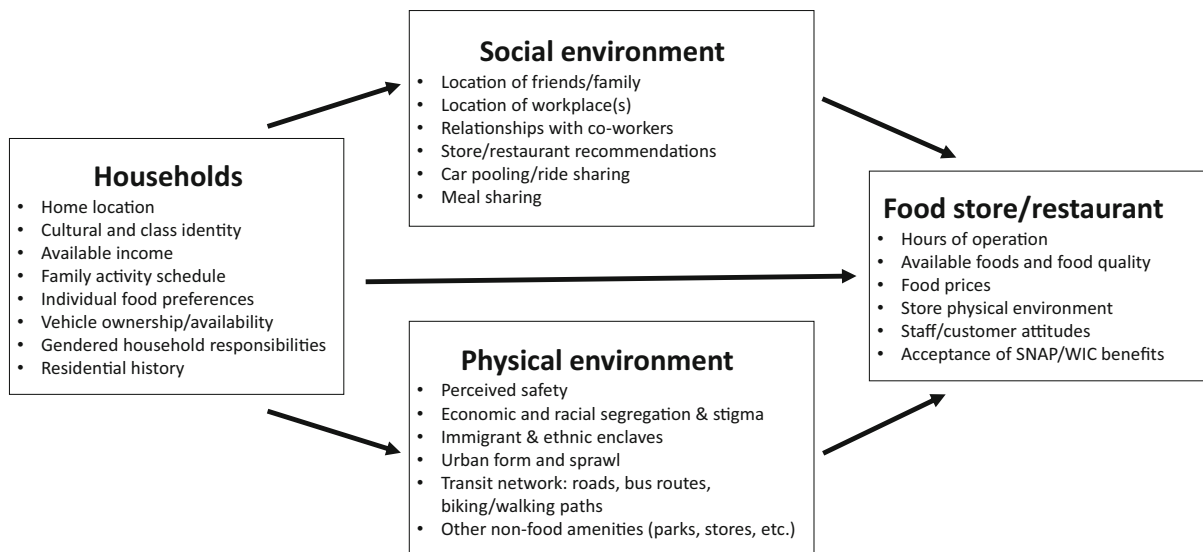
this research identifies connections between the sites that comprise respondents' daily lives. Figure 1 shows our conceptual model of the factors shaping household food procurement, which is influenced not just by qualities of the food stores themselves, but also by mediating characteristics of households' physical and social environments. Locations of home and food stores do shape decisions about food, along with workplace locations and other daily mobility. Other key factors here are more relational, relying less on measures of physical distance. These include past residential histories, perceived neighborhood safety and stigma, characteristics of the urban form, or availability of carpooling/car sharing options. Our analysis makes use of exploratory data analysis (EDA), relying on multiple forms of data visualization to tease out the potential influence of these factors, with the most attention to actual transit use, constraints based on income, the impact of urban form, and the connection between trips to food sources and other destinations. In doing so, we conceive of urban residents as actors whose daily practice both reflects and reinscribes their social, economic, and physical position within a variegated urban environment.

## Methods

### Data, setting, and sample population

This study relies on data from the publicly available 2010 Twin Cities Travel Behavior Inventory (TBI) survey created by the Metropolitan Council, a regional governance body in the Minneapolis/St. Paul, Minnesota metropolitan area.<sup>1</sup> It collected data on all trips made by members of participating households within the region over the course of a single day, including the geocoded locations of all origin and destination points. The exact date varied by household, but all data was for a business day (Monday–Friday), with collection dates ranging from December 2010 through November 2011. In addition to logging the origin/location and time of each trip, the survey collected data on the forms of transit used, the type of place and activity for

<sup>1</sup> More information on this study and a downloadable dataset is available at <http://www.metrocouncil.org/Transportation/Planning-2/Transit-Plans,-Studies-Reports/Other-Studies-Reports/Travel-Behavior-Inventory.aspx>.



**Fig. 1** Conceptual model of factors shaping household food procurement. (Adapted from Shannon 2016)

all sites visited, and demographic data on household participants, including age, sex, income level, educational attainment, auto and bicycle ownership, and employment status. Trip origin and destination points are recorded as latitude and longitude coordinates. These data are publicly available on the Metropolitan Council website in Excel format.

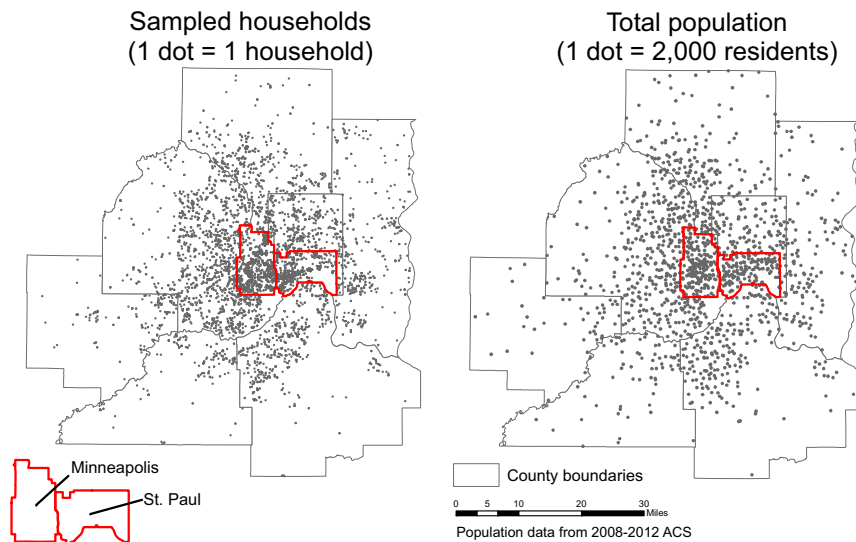
With a population in 2010 of 3.3 million people, Minneapolis/St. Paul has the 16th largest population of all metropolitan statistical areas (MSA) in the United States (United States Census Bureau 2015). In the 2010 decennial census, 78 % of the population identified as white, while 7 % reported African-American, and 6 % Hispanic or Latino, making it less racially diverse than the US population. According to the 2008–2012 American Community Survey, the median household income of the MSA was \$66,804, higher than the same figure for the US as a whole, \$53,046. The Metropolitan Council operates numerous bus routes throughout the area, and at the time of this survey they operated two rail lines.

Table 1 below summarizes several key characteristics of the study sample compared to the Twin Cities MSA, using data from the 2008–2012 American Community Survey. This sample was wealthier, older, and better educated than the region's population. Although low-income households were underrepresented in this sample, the large size of the study still allows for a meaningful comparison across

**Table 1** Selected demographic characteristics of the TBI population sample and the Twin Cities MSA

	Sample (%)	MSA (%)
<i>Yearly income (household)</i>		
<\$25,000	8.2	20.0
\$25,001–\$50,000	15.3	24.3
\$50,001–\$75,000	18.6	20.3
\$75,001–\$100,000	15.7	16.2
>\$100,000	24.6	19.3
Missing/refused	17.6	
<i>Age</i>		
<18	15.7	24.1
18–64	66.4	64.3
65 and greater	17.7	11.5
Missing/refused	0.2	
<i>Education (adults)</i>		
Less than high school	0.1	14.0
High school degree	25.2	23.9
College degree	55.2	62.1
Missing/refused	19.5	

demographic groups. Sampled households have a very similar spatial distribution to the total population, though gaps are clear in the high poverty areas of northwest Minneapolis and north central St. Paul (Fig. 2).



**Fig. 2** Map showing spatial distribution of sampled households against the total population

### Data preparation

The survey provides data on trips ( $n = 79,236$ ), households ( $n = 10,362$ ), and individuals ( $n = 21,298$ ). For analysis, we transformed these data to provide information on tours completed by one or more members of the same household. We defined a tour as a trip or group of trips by one or more individuals where start and end points were either home, work, or the first/last recorded point. These start/end points have been used in other studies of travel behavior (Frank et al. 2007; Kerr et al. 2012). We saw this as preferable to the inclusion of a layover time criteria found in some studies (Schmöcker et al. 2010), given that grocery shopping and dining trips may include long stops and we wished to determine the direction of travel before and after these sites. Aggregating trips resulted in 39,448 distinct tours. Trip characteristics, including time in transit or at stops and mode of travel, were aggregated at the tour level. Network distances for each trip were also calculated using regional roads data with ArcGIS Network Analyst, and the total tour distance was also aggregated at the tour level. Once individual-level tours had been calculated, duplicate tours among members of the same household were combined by identifying duplicate distances, household identifiers, and departure times. We also calculated distance from home to any visited food sources using a network distance to assess proximity independent of other stops or point of tour

origin for comparison to commonly used measures of residential food environment. We used self-reported times from the dataset to measure tour duration, as a comparison of a random sample of 2000 trips against reported travel times from Google's map service showed a close correspondence. The interquartile range of reported times was 45 s to 7 min shorter than Google's calculated time. The final dataset included 30,301 tours with a range of one to five individuals each, though 90 % of all tours consisted of a single person. Of these, 7037 (23 %) had food-related stops. To correspond with store data, only tours occurring completely within the seven-county metropolitan area were retained, resulting in 4975 food-related tours for analysis.

Several studies have shown different patterns of association between these different locations and dietary outcomes, particularly in the case of fast food (Boone-Heinonen et al. 2011; Jeffery et al. 2006; Shannon 2016). To separate these groups, we created two dummy variables for tours, one for grocery shopping and one for eating out, using already existing codes within the data. The former was coded as one if a tour included trips to destinations identified as grocery stores, except when the destination activity was listed as work and not shopping. The latter was coded as one for tours with destinations identified as restaurants/fast food/bar and grill or when the destination activity was listed as eating out.

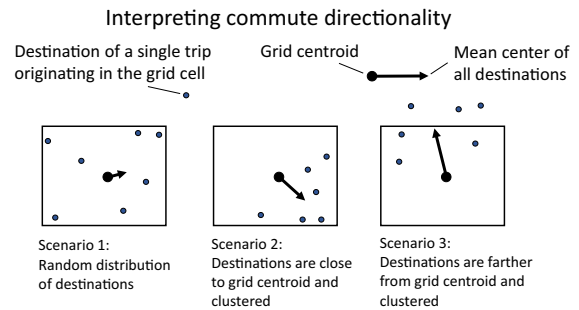


## Exploratory data analysis

To better understand patterns of food access in these data, we adopted an exploratory data analysis (EDA) approach. This method was first formally defined by Tukey (1977), but its popularity has increased alongside the development of computer hardware and software capable of quickly visualizing and analyzing large datasets. Unlike hypothesis-driven statistical modeling, EDA begins with open ended questions, developing a stronger understanding of the distributions and statistical relationships present within a given dataset (Chen et al. 2011; Cox and Jones 1981). This is accomplished through employing a range of visualization and analytic techniques to identify robust patterns and relationships. EDA is a generative process, producing further research questions and new hypotheses, rather than focusing on confirmation or rejection of predetermined hypotheses. Within geography, exploratory spatial data analysis (ESDA) has made use of GIS and various geospatial mapping and analysis methods to identify spatial clustering and statistical relationships (Anselin 1999; Dykes 1998).

EDA has been used in some other research on travel behavior. For example, several researchers have used Hägerstrand's space–time prism as a way of visualizing spatiotemporal patterns in food provisioning over time (Chen et al. 2011; Horner and Wood 2014; Kwan 2000). However, as is the case with research on activity spaces, these approaches focus on absolute measures of space and time, identifying exactly when and where people travel in the city over the course of a day. While this has value, especially for transit planning, our study focuses more on topological relationships within the data. For example, we ask what kind of food trips are most common in the trip between work and home, regardless of when these trips occur. This approach is sensitive to the variety of daily schedules among households and identifies patterns of stops between households, even if those patterns are asynchronous.

We analyzed these data primarily using the open source software package R, which was designed to encourage exploratory data analysis. We investigated several visualization options, including bar charts, violin plots, and density plots to summarize the values of key variables across various population subgroups. We conducted Kruskal–Wallis test or ANOVA and post hoc Tukey HSD testing to determine whether apparent differences were statistically significant,



**Fig. 3** Commute directionality indicates directional clustering and distance from the grid centroid to the mean center of all trip destinations

using a log transformation in the latter case for variables that were highly skewed, such as distance or time, though a large dataset such as this one may be overpowered and risk a type I error.

Additionally, to analyze direction of travel across the metropolitan area, we adapted a areal aggregation technique called *commute directionality* (Hincks and Wong 2009; Nielsen and Hovgesen 2008). In this technique, patterns of spatial flow are calculated by analyzing the direction of all trip destinations from the trips' point of origin. We created gridded datasets at a range of spatial scales and then labeled each tour with its grid ID based on its origin point. We then calculated the mean center of all food destinations used in tours beginning within each grid cell. We created a line was from the center of each cell to the mean center of its food related destinations, which indicated the average distance and direction of all food sources used by the tour origin point. Figure 3 provides a visual explanation of how to interpret the results of this approach. Though we do not show destination points in our results (Fig. 6), Fig. 3 indicates how the directional arrows indicate the overall distribution of these destinations.

To analyze the store environment for grocery shopping, we downloaded a list of participating SNAP retailers from the USDA's SNAP retailer locator.<sup>2</sup> We defined large and mid-sized supermarkets as those with separate meat and produce sections, and identified them primarily through name (for chain stores), in-person observation, and Google Street View imagery [More information available in (Citation withheld for

<sup>2</sup> <http://www.fns.usda.gov/snap/retailerlocator>.

**Fig. 4** Violin plot of median distance from home to food source split by whether tours included stops for food shopping or eating out



**Table 2** Distances in food environment and travel distance across income

HH income	Grocery shopping				Eating out	
	Nearest store	Nearest three stores	Home-food distance	Tour distance	Home-food distance	Tour distance
<\$25,000	1701	3092	3841	9480	7959	12,060
\$25,001–\$50,000	1226	2435	4101	7744	5239	11,807
\$50,001–\$75,000	1587	2926	3809	9784	5906	12,251
\$75,001–\$100,000	1606	3181	4347	12,095	7066	12,803
>\$100,000	1896	3502	4391	10,077	8867	11,644
Income missing	1769	3481	4583	11,250	7546	13,547
<i>Kruskal–Wallis p value</i>	<i>&lt;0.001</i>	<i>&lt;0.001</i>	<i>0.189</i>	<i>0.117</i>	<i>&lt;0.001</i>	<i>0.088</i>

Table shows mean distance in meters (network distance)

blind review)]. We calculated network distances to the nearest store and nearest three stores for each home listed in the study to serve as proximity- and density-based measures of the accessibility of food stores (Apparicio et al. 2007).

**Results**

Relationship to home/tour origins

To provide context for the food shopping described in our survey data, we measured network distance from home to all visited food sources, independent of the actual tour path. This method was used to facilitate comparison with conventional distance based measures of the food environment. The distributions of this home-food distance variable varied significantly

between grocery shopping and trips for eating out. The violin plot in Fig. 4 shows the distribution of home-food distances for each type of trip. Though both are positively skewed, the distribution for eating out has a thicker tail than that for grocery shopping, demonstrating that individuals often traveled farther from home to eat out. Likewise, the more compressed distribution of grocery store distances shows a closer association with residential location. The median values for the home-food distances for eating out and grocery shopping were 7.6 and 4.2 km, respectively, and a Wilcoxon test shows a significant difference between the groups ( $p < 0.001$ ).

Table 2 displays a tabulation of median home-food distance across income. Columns 1–3 compare the actual distance travelled for grocery shopping with the distance to the nearest grocery stores. In most cases, actual home-food distance is similar or slightly greater than the

distance to the closest three stores. The association between household income and the distance between home and food sources is significant for eating out, but not for grocery shopping. For the latter, median home-food distance ranges between 3.8 and 4.6 km, a difference that is not statistically significant ( $p = 0.189$ ). For eating out, values range from 5.2 km for households with an income of \$25,000–\$50,000 to 8.9 km for those with >\$100,000 in income ( $p < 0.001$ ).

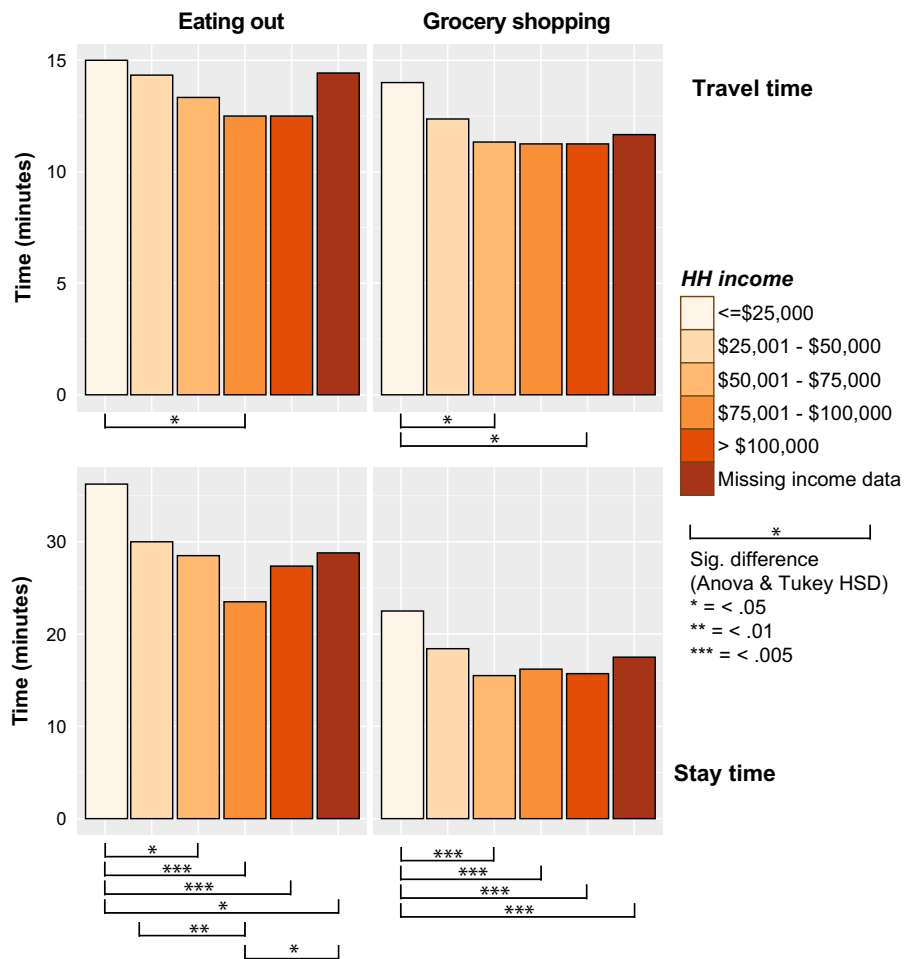
Our analysis of the time spent in travel to locations (travel time) and at locations (stay time) revealed other trends. The median times per stop for each income group and trip type are compared in Fig. 5, where a bar graph displays the median value for each group. ANOVA and follow-up Tukey HSD tests using logged variables identified significant differences among groups, and these are identified with square brackets below each graph. We found that for the lowest income

**Fig. 6** Commute directionality of tours subdivided by point of origin and income

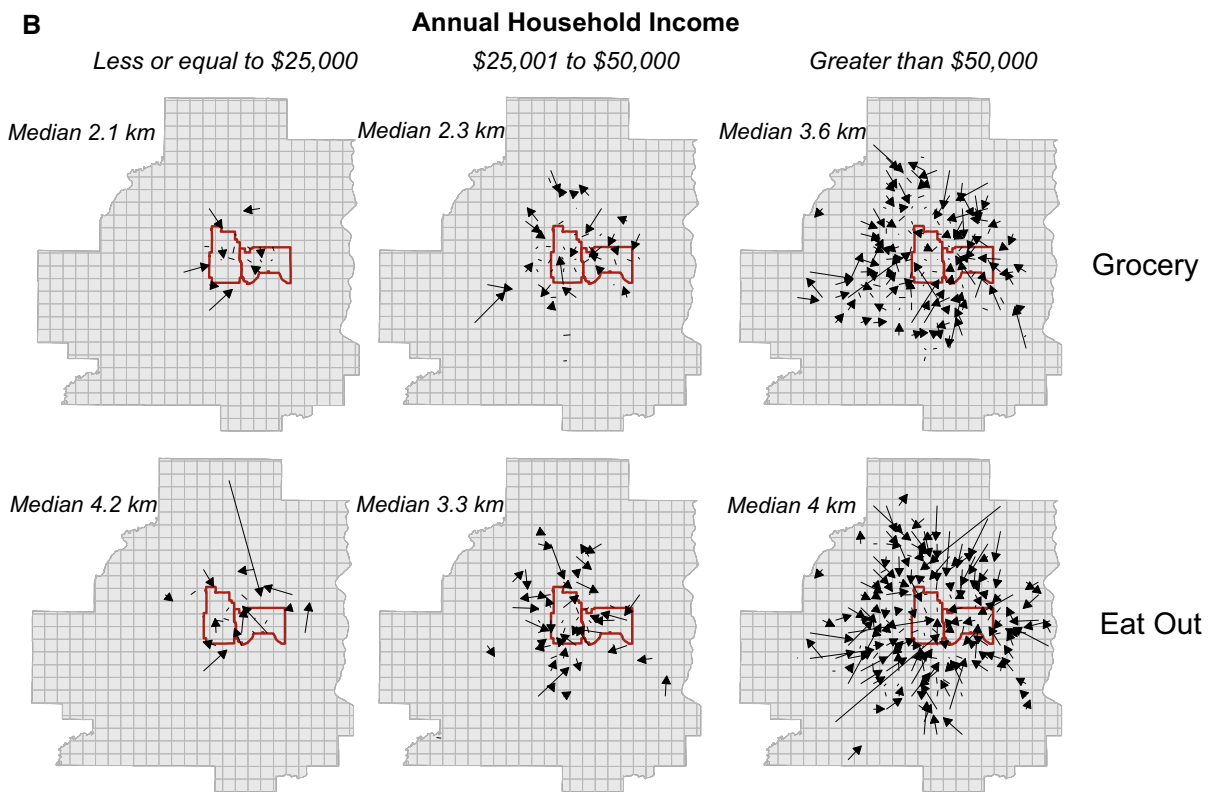
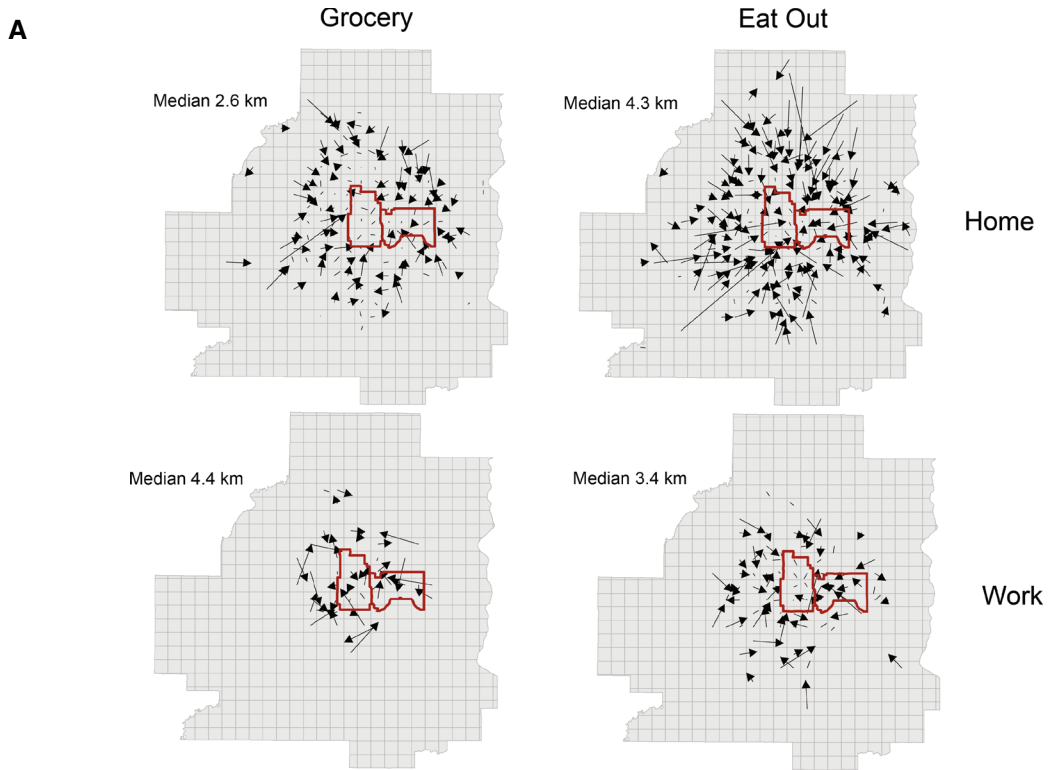
group, both stay times and travel times were significantly longer than for other households in all four graphs, though these differences were more pronounced for stay times. This trend is notable given the lack of a similar pattern in distance travelled to food locations or total tour distance across incomes in Table 2. Thus, the time and opportunity costs of food shopping/dining out would appear to be larger for lower income groups.

Our analysis of commute directionality finds significant spatial patterning in food-related mobility. Figure 6a shows four maps, which display tour data by type of tour (for grocery shopping or eating out) and the type of origin point (home or work). The grids used in this analysis are 4 km × 4 km, though these patterns were

**Fig. 5** Median time to location and at location for food related tours by household income and trip type







robust across scales. Only grid cells with 3 or more food destinations were included. The first row, tours originating at home, shows a trend of shopping that moves toward the two central cities. As we discussed above, the median distance to eating-out destinations was twice as far as the distance to grocery stores. In Fig. 6a, the longer lines for home-based eating-out tours illustrates this trend. Also, tours originating in suburban areas often involved notably greater movement toward the center city. Tours originating in Minneapolis and St. Paul, at the center of these maps, show few clear trends. Rather, tours in these areas spread in multiple directions, perhaps reflecting the denser settlement patterns of the urban core and less division between commercial and residential properties. While some trend lines stand out in the work-related tours on the bottom row, we see no clear pattern in the direction of those lines across the region. These maps, then, primarily show patterns of movement from the edge of the city toward its core for home-based tours.

Figure 6b subdivides tours by three broad income categories. Since both Figs. 4 and 6 show the strongest income effect on travel for the lowest groups, we have collapsed upper income households on this graph to keep these maps large enough to be legible. For households with annual incomes at or below \$50,000, the median distance for grocery shopping between tour origin and mean destination point was notably lower than it was for the upper income groups (2.1 and 2.3 km vs. 3.6). Conversely, for eating out, the lowest income households had the largest median distance (4.2 km) while households with \$25,000 to \$50,000 had the lowest median distance (3.3). Despite the larger median trip distance, however, the lowest income households largely saw their travel constrained to the areas immediately surrounding Minneapolis/St. Paul boundaries, while higher income groups were more likely to travel in suburban areas. Travel still often was oriented toward the city center, with this pattern most pronounced for eating out in higher income households.

#### Means of transit

Automobiles were the primary means of transportation on food related tours. For households with incomes above \$25,000, 93 % of all tours involved a car at some point in the tour. That figure dropped to 79 % for households earning less than \$25,000, a significantly

smaller figure but still a sizable majority of all tours. For households without a vehicle, only 38 % of food related tours involved a car. The trend of lower automobile use for the lowest income category is clear in the first row of Fig. 7, which summarizes transit use in this sample, stratified by income. Use of public transit, shown in the second row of Fig. 7, was significantly higher in low income households, with 11 % of tours involving transit, compared to only 2 % for all other households.

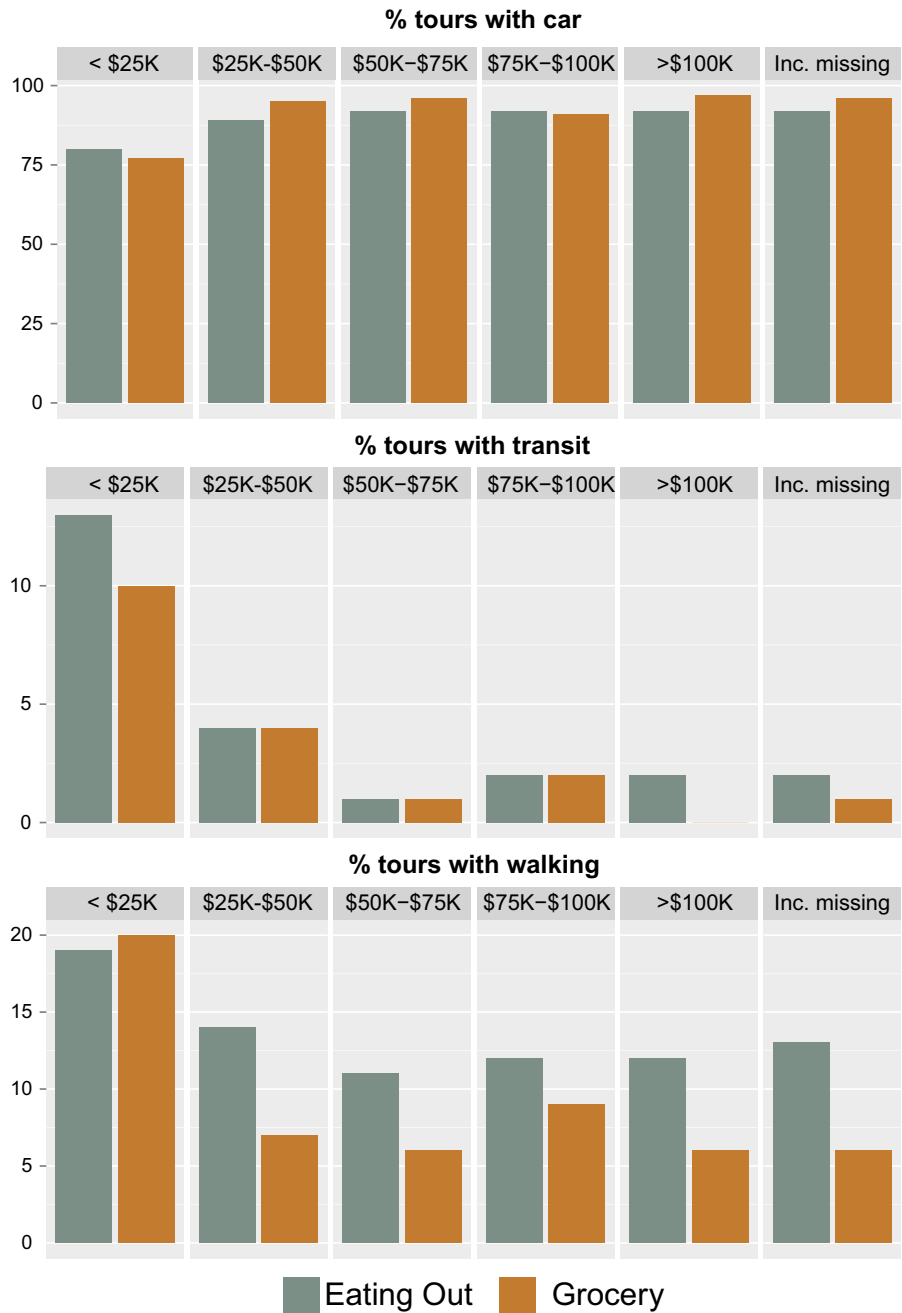
Walking was more evenly reported across income groups, especially for tours that included eating out. While still more common (19 % of tours) for the lowest income households, 10.3 % of tours from households with incomes above \$25,000 involved walking. Unsurprisingly, walking was more common in the urban core. Only 5 % of tours involved walking among households in neighborhoods with the lowest population density (bottom 40 %), compared to 17 % among households in neighborhoods with the highest density (top 40 %). Walking was also often part of multi-modal tours. In tours that included walking, 39 % also included auto travel, and 14 % included some form of public transit.

Figure 8 shows commute directionality broken out by means of transportation. The median distances here show that tours relying only on automobiles were longer than those relying on other forms of transit. This may be explained in part by the fact that the latter group was concentrated largely in the dense urban core, while tours originating in sprawling suburban areas were significantly longer in length. Automobile tours had a strong orientation toward the city center, especially for tours that included eating out, but this was not true for tours using other forms of transit.

#### Food shopping and daily mobility

Our analysis also explored how food shopping was related to other forms of daily mobility. As part of this analysis, we separated tours into categories based on the origin and destination points. Figure 9 shows the distribution of tours based on this classification. The majority of tours began and ended at home, with a greater percentage of grocery tours (75 vs. 62 % for eating out) falling into this category. Eating out was more common to trips to work (7 vs. 2 % for groceries) or during work (16 vs. 2 %), with the latter probably reflecting a lunch

**Fig. 7** Mode of transportation by income for food related tours

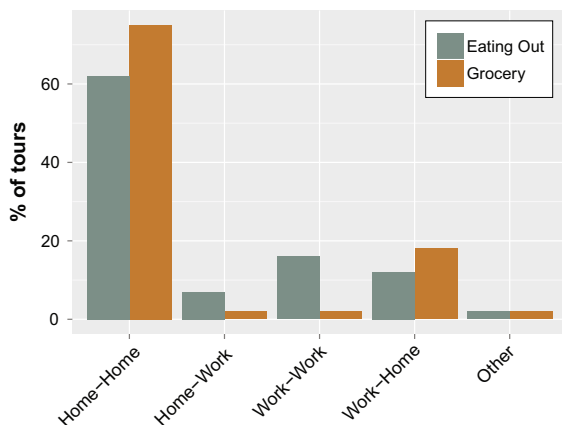
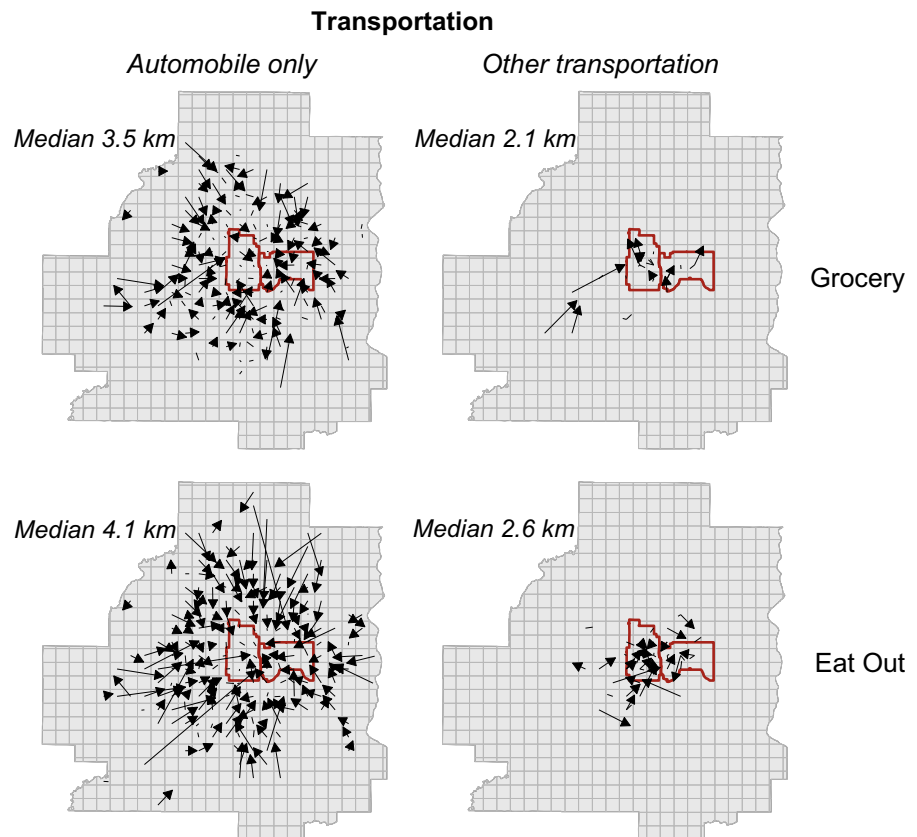


break. Trips from work to home included both eating out (12 %) and grocery shopping (18 %).

Figure 10 uses these same categories to compare distance from home to food source against total tour distance. Work-work trips, those presumably happening mainly over a lunch break, have the shortest median tour distance (2.9 km), but the longest home to food source

(15.7 km). This likely reflects trips to restaurants close to individuals’ workplaces. The longest tour distances are on journeys to or from work (20.5 and 21.4 km, respectively). While the distances between grocery shopping and eating out are similar on the way to work, on the return home eating out has longer tour distances (25.3 vs. 18.1 km) and longer home to food source

**Fig. 8** Commute directionality subdivided by means of transportation

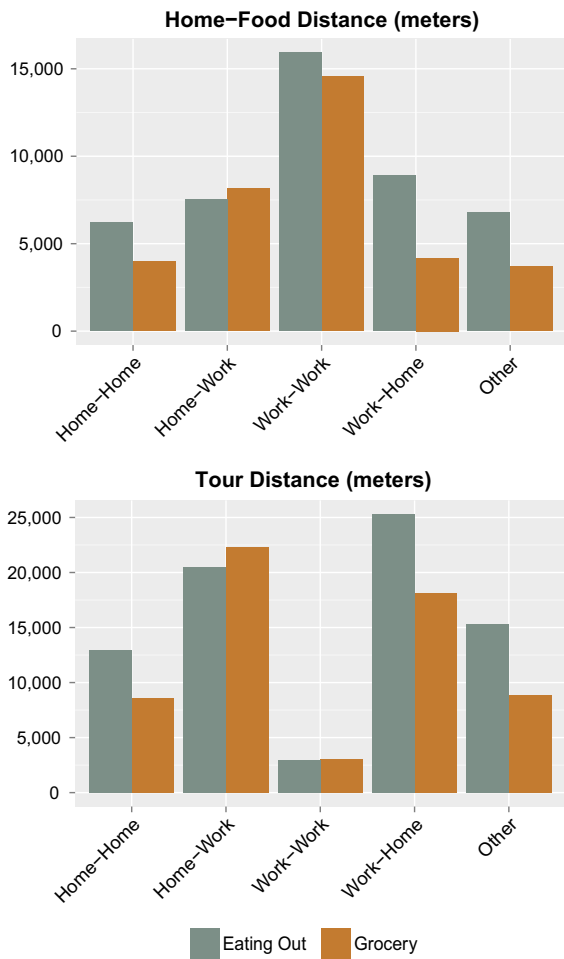


**Fig. 9** Tour distribution by tour origin and destination

distances (8.9 vs. 4.2 km). This may show that tours for eating out after work may extend further from home. The distances for grocery shopping tours before and after work are similar (7.5 vs. 8.9 km for home to food distance, 22.3 vs. 18.1 km for tour distance), suggesting

that these may follow a similar commuting route. Trips that begin and end at home have shorter median home-food distances, 4 km for grocery shopping and 6.2 km for eating out. However, these distances still extend beyond what might normally be considered the residential neighborhood.

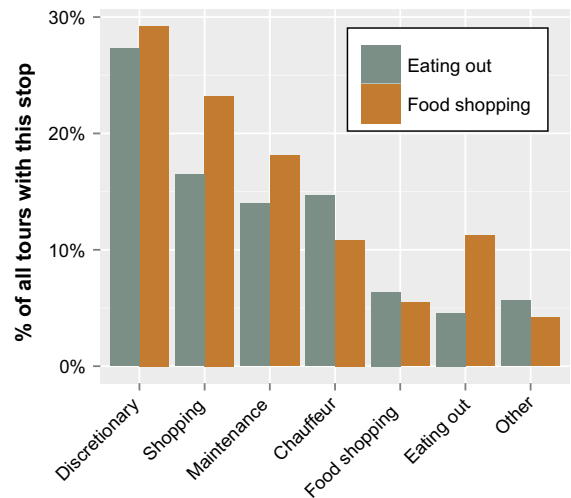
Food shopping was also rarely the only activity on food related tours. For tours with eating out stops, 55 % included another destination. This was true for 63 % of tours including grocery shopping. The data provide only limited information on activities at other stops on these tours, but their frequency is summarized in Fig. 11. The most frequent other stop is listed as discretionary (27 % of all tours), which largely consists of leisure activities such as visits to friends and family, exercise, visits to parks, and religious services. Other shopping trips were also common, but more so among tours for grocery shopping (23 %) than those for eating out (17 %). Trips for maintenance, which included errands such as medical appointments, visits to the bank or city government, or hair styling,



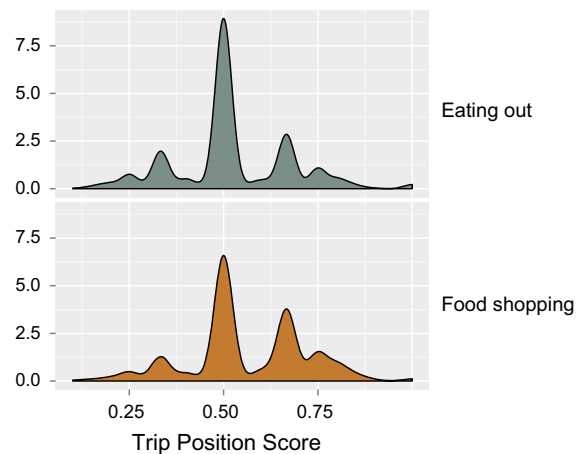
**Fig. 10** Home to food source distance and tour distance by tour origin and destination

had higher rates on grocery shopping tours (18 vs. 14 %). Trips as a chauffeur—driving a friend or other family member to an event—were one of the few with higher frequency when paired with eating out (15 vs. 11 %). This graph only counts additional stops for food related destinations, meaning that only 5 % of eating out trips included an additional stop for eating out, but 11 % of food shopping trips included any stops for eating out. Similarly, 6 % of food shopping trips included another food shopping stop, and 6 % of tours for eating out included a food shopping stop.

Lastly, we also examined where food stops were located within tours. To do so, we developed a metric we term the *trip position score*. This measure is the ordinal position of the stop within a tour divided by the



**Fig. 11** Percentage of food-related tours with stops at other destinations, divided by tour type



**Fig. 12** Density plot of the trip position score, subdivided by type of food source

total number of stops. For example, if the total tour length was five stops and the food source was the 3rd stop, the trip position score would be 0.6 (3/5). A tour of three stops where the food source was the first stop would have a score of 0.3 (1/3). This metric standardizes the food stop location across tours of varying lengths. To visualize the distribution of the trip position score, we created a density plot, shown in Fig. 12. This plot shows that food stops tended to be in the middle of tours, though more stops were located toward the end of tours than the beginning. Furthermore, while the two plots have a similar shape, eating

out was more likely to be the middle stop of a tour than grocery shopping, as the peak at the mid point was higher in this graph and the peaks of scores  $>0.5$  were smaller in magnitude. On trips with four stops, for example, 52 % of grocery trips happened on the third stop, compared to 36 % of eating out trips. Similarly, 31 % of grocery trips happened at the second stop in a four stop tour, compared 38 % for eating out trips.

## Discussion

Our research develops a relational analysis of how food provisioning is positioned within the everyday practices of urban residents. The results confirm that the residential food environment, narrowly defined, plays a limited role in households' food provisioning practices. Most individuals travelled significantly farther than the nearest grocery store to shop for food. The median distances to groceries ranged from 3.8 km in low income households to 4.4 km in the highest income ones. For eating out, these figures were 8 and 8.8 km, respectively, suggesting that for many, eating out is an activity often done far from home, perhaps when eating at home is practically difficult. The data do not allow us to identify whether eating out happened at fast food establishments or sit down restaurants, and prior evidence on the effects of fast food specifically on dietary outcomes has been inconsistent (Fleischhacker et al. 2011). These results do show that interventions to improve healthy food options in low income areas must look beyond the immediate residential neighborhood.

Household income did have an effect on food provisioning in this study. Automobile use was significantly lower for households with incomes under \$25,000, and use of both transit and walking were more frequent. Both travel and stay times on food related tours were longest for these households and shortest for higher income groups, suggesting that the constraints of lower incomes—such as limited access to reliable transportation—increase the time and opportunity costs of food shopping. Low income households were more likely to rely on public transit or walking on food related tours, though automobile use was still common. Use of alternative transit was most common in the urban core, whereas automobile use was unsurprisingly more common in suburbs. Given the increasing rates of poverty in suburban areas, including the Twin

Cities, this suggests need for more diverse transit options outside the central city for households with limited vehicle access (Kneebone and Berube 2013). In contrast to existing policies aimed at increasing the number of retailers in residential neighborhoods, these results show that transportation and its associated costs should be targeted in interventions to improve food accessibility for low income groups.

Our analysis also shows how food shopping is related to other patterns of daily mobility. The majority of both grocery and eating out trips started and ended at home, however eating out was more common in work related tours, presumably due to the time constraints of a meal break. Even for trips after work, though, the larger distance to eating out destinations shows that work, and its related social ties, acts as a second anchor for food-related activity, supporting research incorporating workplaces into analysis of the food environment (Widener et al. 2013). This further implies that interventions attempting to improve healthy food accessibility should focus on the composition of commercial and business districts, rather than residential neighborhoods, as these may spatially structure available food options for time constrained individuals.

Other daily tasks, whether for recreation or for errands, were also associated with food related tours, with slightly higher frequencies of this trip chaining in grocery shopping tours. Future analysis might focus not just on how food sources are positioned relative to individual activity spaces, but also their proximity to other services, including other forms of shopping, green space, or healthcare providers. The placement of eating out near the middle of many participants' tours—when they are presumably farthest from home—also demonstrates that the location of other urban amenities (e.g., non-food stores, business centers, parks) may determine where individuals dine more than their own residential location.

Our research is limited by several factors. Though it draws upon a large sample, it is only for one metropolitan area, and the results may not be generalizable to other cities or regions. Rural areas may also show different patterns of food-related mobility. The sample population for this study was skewed toward the least vulnerable populations, and while we still were able to find significant results for low-income groups, a more representative sample may have yielded slightly different results. We have admittedly limited data on study participants: only a single travel



day, without information on the specific stores they visited or the items they purchased. Future research could match stops to stores based on location, but the accuracy of these matches would be difficult for large retail centers where stores may be spatially clustered. Our data also lacked information on self-reported race, even though racial identity may influence mobility within segregated urban spaces (Tana et al. 2015).

By focusing primarily on topological characteristics of this travel survey, our analysis provides insight on how food provisioning is embedded within and constrained by individuals' everyday activities, their economic positionality, and their location within the urban landscape. Multiple aspects of our analysis, including commute directionality and trip position, are new or rarely used techniques for measuring food access patterns. While we identify several significant relationships within these data, the mechanisms for these relationships are often unclear. More targeted studies could focus on what accounts for longer distances for eating out or how food shopping is connected to other categories of activity. Through this research, we might gain a stronger understanding of how individuals' interactions with their physical, economic, and social environment impact food purchasing and consumption decisions. Furthermore, while other current research is examining how new neighborhood stores impact shopping and dietary behaviors (Cummins et al. 2014; Elbel et al. 2015), similar work could be done for transit-based interventions such as redrawing bus lines to improve easy access to food sources or locating large local markets near nodal points in the transit system. By incorporating measures of daily mobility, future research on food access might suggest interventions that both improve nutrition and create more livable communities.

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#### Compliance with ethical standards

This research is based on a publically available secondary dataset we obtained from a government source, and thus our work involved no direct contact with human subjects or release of sensitive information.

**Conflict of interest** We have no conflicts of interest in publishing this research.

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