ACCESSIBILITY AND COGNITION:
THE EFFECT OF TRANSPORTATION MODE ON SPATIAL KNOWLEDGE

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ABSTRACT
Cognitive mapping is central to spatial behavior and decision making. The cumulative process of spatial learning, during which cognitive maps develop primarily through wayfinding and travel experience, affects accessibility by determining whether and how destinations are encoded into one's cognitive map. In this paper, we examine whether differences in cognitive maps can be explained, in part, by variations in travel mode. To test our hypothesis, we surveyed adults in a low-income Los Angeles neighborhood with relatively low auto use and high transit use. Our data show that variations in cognitive mapping and spatial knowledge do indeed vary between individuals and among groups in systematic ways. Some of these differences are related directly to previous travel experience, including experience with travel modes. We conclude that variations in spatial knowledge can result in radically different levels of "functional accessibility," despite similar locations, demographics, and other factors commonly thought to influence travel behavior. A better understanding of the complex relationships among spatial cognition and travel can help guide policymakers, planners, and transportation analysts in improving accessibility to employment, services, recreation, and other important destinations.

Keywords: Cognitive mapping; spatial learning; travel behavior; travel mode.

1. INTRODUCTION

Both a process and a product of the mind, cognitive mapping is essential for spatial behavior and decision-making (*1, 2*). Some transportation researchers have explored cognitive mapping on the premise that travel and transportation systems are influenced by, and themselves influence, spatial cognition (*3, 4*). While most of this transportation research focuses on cognitive mapping's influence on route choices, we hypothesize that the relationship between travel and spatial cognition extends beyond path selection to other aspects of travel. Cognitive mapping encompasses individuals' knowledge not only of potential travel routes but also of destinations themselves, as well as their proximity, purpose, desirability, and familiarity. Therefore, spatial cognition also shapes individuals' access to opportunities. The cumulative process of spatial learning, during which the cognitive map develops primarily through wayfinding and travel experience, affects accessibility by determining whether and how destinations are encoded into one's cognitive map.

We examine whether differences in cognitive maps can be explained, in part, by variations in travel mode. We suspect that one's image of the city, perceptions of activity locations, and the paths linking opportunities are profoundly shaped by whether one typically navigates the city by foot, bicycle, bus or train, behind the wheel of a car, or as an auto passenger. For example, walking and bicycling typically involve more intimate and slower speed interactions with places than traveling by train or private vehicle. Likewise, walking, bicycling, and driving all require the traveler to actively make wayfinding decisions throughout a trip, while bus, train, and auto passengers are more passively chauffeured by others for significant parts of their journeys. These differences in modal experience are at times stark, and may create significantly different perceptions of cities and their opportunities among different travelers.

To test our hypothesis, we surveyed adults in a low-income Los Angeles neighborhood, where auto use is lower and the variety of travel modes used is large. Our data show that variations in cognitive mapping and spatial knowledge do indeed vary between individuals and among groups in systematic ways. Some of these differences are related directly to previous travel experience, including experience with travel modes. Hence, we conclude that variations in spatial knowledge can result in radically different levels of "functional accessibility," despite similar locations, demographics, and other factors commonly thought to influence travel behavior. A better understanding of the complex relationships among spatial cognition and travel can help guide policymakers, planners, and transportation analysts in improving accessibility to employment, services, recreation, and other important destinations.

This paper is divided into four sections. Following this introduction, the second section examines cognitive mapping, its role in spatial learning and decision making, and the relationship between cognitive mapping and travel. The third section describes our research, survey data, and findings. The final section explores potential implications of this research to transportation planning and policymaking.

2. COGNITIVE MAPPING, SPATIAL LEARNING, AND TRAVEL BEHAVIOR

2.1 Components of the Cognitive Map

Downs and Stea define cognitive mapping as a construct of "cognitive processes which enable people to acquire code, store, recall, and manipulate information about the nature of their spatial environment," enabling individuals to engage in "the adaptive process of spatial decision making" (*2*). Cognitive mapping relates perceptions and preferences within a spatial matrix, allowing individuals to make decisions in a spatial context (*5*).

A cognitive map – the result of the cognitive mapping process – includes spatial information about the environment, including places' and routes' identity, location, distance, and direction (*6*). Both person-to-object relationships and object-to-object relationships are contained within the cognitive map (*7*). Because cognitive mapping internalizes geography, the temptation to interpret a cognitive map as a mental version of a cartographic map is strong (*8*). However, there is no simple, one-to-one relationship between cognitive mapping and cartographic space. Instead, the cognitive map should be taken as a metaphor for a cognitive construct that is much less literal than a cartographic map (*9, 10*). The incomplete and error-prone nature of cognitive mapping causes variability between the cognitive maps of individuals and serves to explain the "bounded rationality" of spatial behavior (*7*). Still, error and incompleteness are not completely random in individuals' cognitive maps. Rather, variations across individuals are partly due to factors like experience, social processes, and demographic differences.

2.2 Spatial Learning

Spatial learning occurs in a progression from "landmark" to "route" to "survey" knowledge (*11*). After learning a landmark, isolated landmarks are linked in routes, but individual routes in the cognitive map remain largely unrelated. With greater experience and spatial facility, more systematic knowledge of the environment can be learned, often called survey or configurational knowledge (*8*). This type of knowledge incorporates isolated routes into a system. As linkages are made between individual routes and locations, increased functionality is added to the cognitive map, such as the ability to devise shortcuts between destinations and create complex trip chains.

Not all individuals reach the same level of cognitive map development (*12*). Cognitive mapping develops over time, changing with age and experience (*2*). Differences in individuals' spatial abilities explain some differences in the development of cognitive mapping, such as the ability to think geometrically, image complex spatial relations, recognize spatial patterns, and understand network structures (*7*). Such capabilities are partly innate, but researchers have also found that they can be developed and extended through training and use (*7*). Social and economic differences are another potential source of variation across groups and individuals. Factors include social and cultural characteristics, education, and income (*13, 14*). Banerjee and Baer, for example, found that that different socioeconomic groups tended to draw different size neighborhood maps, and that such variations in neighborhood map size reflected not only different spatial locations in the city but the varied level of mobility and access associated with different communities (*15*).

2.3 Cognitive Mapping and Transportation

Cognitive maps are acquired, primarily, through travel and interaction with transportation systems. These cognitive maps, in turn, influence travel (*3*). Golledge and Stimson propose a path-based theory of spatial learning giving travel and navigation primary roles (*7, 13*). The cognitive process of wayfinding allows humans to expand their cognitive maps through search, exploration, and incremental path selection (*4*). Each of these activities allows individuals to learn about their environment (*6*). As the product of the wayfinding process, route-based knowledge is considered the most basic type of spatial knowledge (*8*). Landmarks and routes between places and/or people are usually the first things learned when traveling through a new environment. "Environmental cues or other features of the environment have the highest probability of being perceived and recognized if they are in the immediate vicinity of choice points," locations where individuals make some necessary decisions in navigation, such as direction changes (*7*). Therefore, individuals are most likely to learn about opportunities in the environment if those opportunities are near choice points. Hence, nodal points in the transportation network are important locations in the landscape of daily life.

Little is known about how the existing transportation infrastructure shapes cognitive maps and, in turn, affects route selection as well as other aspects of travel including trip frequency, purpose, destination, and mode choice (*4*). The limited available research suggests that transportation infrastructure and wayfinding on overlapping, yet distinct, modal networks – sidewalks, bike lanes, transit routes, local streets and roads, and freeway networks – affects the development of cognitive maps and, in turn, travel behavior. For example, the more significant a particular pathway or landmark is to one's navigation, the more it will dominate the cognitive map (*7*). The hierarchies of pathways in a region, like highway and freeway segments dominating arterial and main roads, which in turn dominate local community and neighborhood street systems, contribute to the hierarchical organization of cognitive maps. Zannaras also found that the layout of a city significantly explained variations in the accuracy of wayfinding and location tasks (*16*). Sectorally-organized cities proved more effective for remembering locations, while concentrically-organized cities made wayfinding and location tasks more difficult. Likewise, familiarity, or "route learning," is an important part of both route selection and mode choice because familiarity is dependent on repeated experience. Stern and Portugali (*17*) highlight two aspects of route familiarity: [1] specific experience of a given locality and [2] general familiarity with city structures, the hierarchy of roads, traffic and signage. Those who use different modes will develop different degrees of familiarity with each transport system. Such research suggests those who use different travel networks, such as auto and transit users, will understand the same urban environment in different ways.

Much of the scholarship on cognitive mapping has focused on drivers and the street and highway network (*18*). Nevertheless, preliminary evidence suggests that cognitive maps are shaped differentially by alternate modes. For example, we know that individuals relying on public transit or walking, on average, travel shorter distances and less frequently than those traveling by motor vehicle. Therefore, one can hypothesize that the scope of their spatial knowledge would be more limited and differently configured (by, for example, the network of transit routes) than those who rely on automobiles and can travel longer distances at greater flexibility and speed.

The quality and detail of spatial maps also may differ by mode. In a study of children traveling to school, "active" modes of travel, such as walking and biking, appear to contribute more to the development of spatial knowledge than passive modes of travel, such as being chauffeured by an adult or riding in a school bus (*19*). These results suggest that variation in transportation mode may result in different levels of functional accessibility for individuals from otherwise similar backgrounds. Research also suggests that travel behavior is influenced by perceptions of distance which affect "the decision to stay or go…the decision of where to go…[and] the decision of which route to take" (*20*). Cognition of environmental distance is influenced by pathway features, travel time, and travel effort which are substantially different depending on travel mode (*21*). The characteristics of travel by transit, which include indeterminate waiting at transfer points and walking trips between services, may add to cognitive distance in ways that auto travel does not.

2.4 Implications for Accessibility

Drawing on a path-based theory of spatial learning, variations in cognitive maps across socioeconomic groups may be explained in part by the different travel patterns of those groups. Certainly, adults in higher-income households are more likely to have reliable access to automobiles than adults in low-income households. Over one quarter of low-income households do not have automobiles and are transit dependent (*22*). But transit use is also high among adults in low-income households with automobiles since oftentimes there are too few vehicles to accommodate the number of household drivers.

In addition to the role that cognitive maps play in explaining wayfinding and route choice, we hypothesize that travel by different modes systematically manifests in individuals' cognitive maps structured more by transit networks (i.e. transit lines, stations, and stops) than by the arterials, collectors, and local streets that make up urban street networks. In other words, a modally-specific wayfinding experience significantly and systematically influences the formation of cognitive maps. And these maps, in turn, influence trip generation, trip distribution, and mode choice.

3. RESEARCH

To test our hypothesis that the experience of travel mode shapes the cognitive map and, hence, functional accessibility, we collected survey data from respondents in South Los Angeles, an area with relatively low levels of private vehicle access and substantial use of other modes. We compare the responses of individuals, grouped by their dominant travel mode, to questions designed to extract spatial knowledge from their cognitive maps. As we show below, we find that travel mode does have an effect on how individuals think about their environment and that variations in cognitive mapping do influence how individuals perceive the accessibility of destinations in their environment.

3.1 Methodology

To address our research questions, we designed a survey to extract information both on travel behavior and spatial knowledge. The in-person survey was conducted in South Los Angeles at the Kenneth Hahn Shopping Center, a large commercial center directly adjacent to the Rosa Parks Transit Center. Two light rail lines and nine local and express bus lines converge at the transit center, supplying the shopping center with a relatively high proportion of transit users compared to their numbers in Los Angeles overall. In addition to the abundance of transit users, the South Los Angeles location is particularly appropriate because its population is relatively poor and minority, groups for whom accessibility is a primary concern. Figure 1 illustrates the site in relation to the adjacent transit center and its regional context.

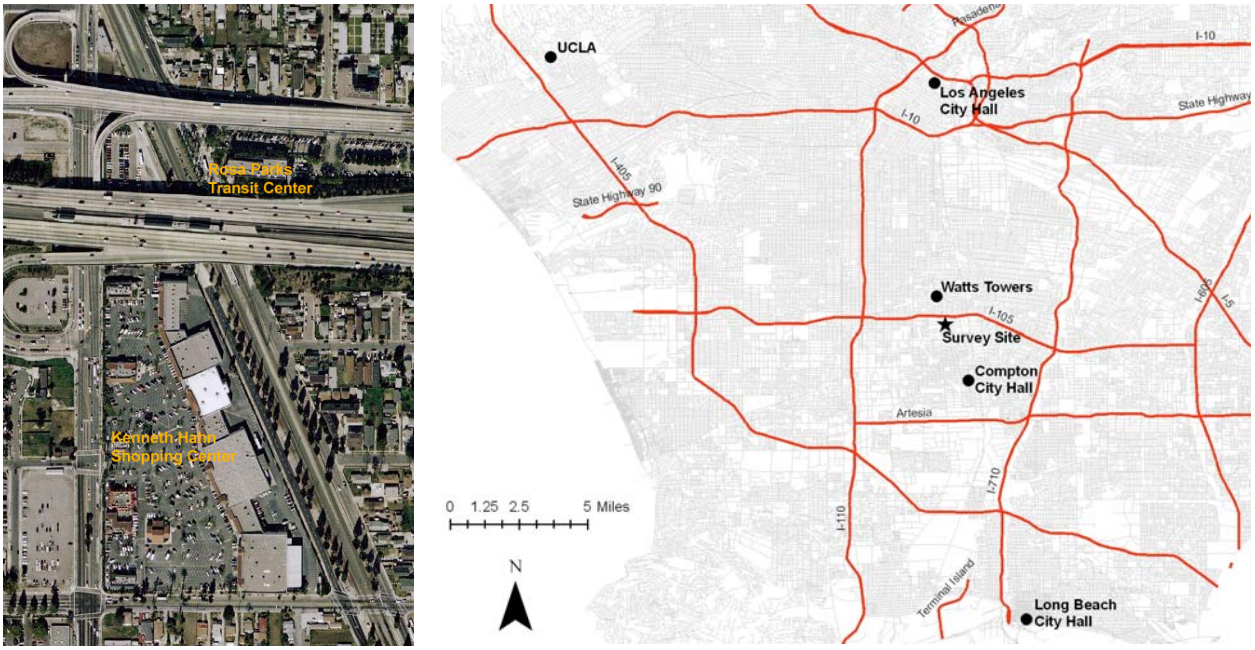

FIGURE 1 Aerial view and regional context of survey site and adjacent transit center.
(sources: Google Maps and US Census Bureau)

The survey was administered in both English and Spanish. Unless already assisting a respondent with a survey, surveyors approached all potential respondents passing them in high-traffic locations in the shopping center. Participation in the survey was encouraged with a ten-dollar gift card to Starbucks, a vendor in the shopping center, and approximately one third of those approached participated. In total, ninety-five responses were collected during two Friday afternoons in May 2007, with each response taking approximately 10 minutes to complete. The diverse set of modes utilized by respondents (see Table 1 for sample size by mode) allows us to investigate our hypotheses regarding the relationships between cognition and mode.

Numerous methodologies have been developed for extracting empirically analyzable spatial products from cognitive mapping (*7*, *13*), none of them simple or easy. Cognitive maps are, by definition, abstract phenomena, and consistently representing these maps across respondents is an epistemological challenge. The spatial products generated by available methods draw upon the complex geometries, orientations, perceived quantities, and qualitative characteristics contained within a cognitive map. The variety and overlapping purposes of many methodologies suggest that employing a diverse set of techniques to extract cognitive information is preferred (*23*).

We asked several questions about our primary independent variable, travel mode, and primary dependent variable, cognitive mapping, in order to mitigate the danger that the particulars of survey design influence the results more than the constructs we actually seek to investigate. To extract cognitive information, we employed an array of data collection techniques, including questions about the location of destinations, the distance to generic and specific destinations by both absolute and relative measures, and sketch mapping routes to generic and specific destinations. To understand how travel mode dominates an individuals' cognitive mapping over the lifespan, we ask questions about mode traveled that day, mode to employment, mode to hypothetical destinations, and the availability of autos to a respondent. We questioned about time residing in one's neighborhood and socio-economic status including age, education, nativity, race/ethnicity, and sex.

3.2 Results

Our analysis explores the relationships among spatial knowledge, travel mode, and accessibility revealed by our survey of adults in South Los Angeles. We find that, indeed, the experiences encoded within individuals' cognitive maps produce differences in how individuals think about their environment. Specifically, we find preliminary evidence that travel mode affects how individuals perceive the built environment, both in how they estimate distance and in the relative refinement of their cognitive maps. In this paper, we explore how cognitive measures in the survey vary across modally-defined groups. We primarily utilize descriptive statistical approaches, highlighting the robustness of evident trends across different versions of the independent and dependent variables. While other cognitive effects are evident in the results, they are uncorrelated with the effect of travel mode.

3.2.1 Respondent Characteristics

The neighborhoods surrounding our survey site are a mix of poor and working-class African-American and Latino households. The census tract encompassing the shopping center is precisely 50 percent non-Latino African American and 50 percent Latino (*24*). A large share of the Latinos is immigrant and undocumented, presenting an enormous challenge to survey research, where the government affiliation of the surveyors (as state university employees) and university-mandated human subject consent forms prove intimidating to non-English-speaking and/or undocumented residents. As such, just 5 percent of respondents in our sample were born outside the United States and 77 percent were African American, resulting in a relatively homogenous population in terms of race, ethnicity, and nativity upon which to test variations in cognitive knowledge and travel behavior. Importantly, key characteristics that may explain variations in cognitive mapping and spatial knowledge are relatively equally represented across modal groups. All groups, other than the small "other" group, have lived in their current neighborhood on average for more than 10 years. For all groups, average age, percent female, and average grade completed are similar. The relative similarity in socio-economic status between modal groups suggests that differences found in cognitive measures should not be confounded by these characteristics.

3.2.2 Distance Estimation by Mode

Distance estimation is a common technique employed to extract information from individuals' cognitive maps. In this survey, all respondents were asked to estimate the distance from the survey site to Los Angeles City Hall. This measure provides information both about the accuracy of cognitive mapping with regards to distance and the prominence of a particular location in the cognitive map. Asking a distance question from a common, known point (the shopping center) to a well-known landmark (City Hall) serves to minimize unfamiliarity with the route and increase comparability across respondents. The shopping center and City Hall are both located at major transit nodes, so relatively direct travel is possible by both public transit and private vehicle, and actual travel distances (if not travel times), are quite similar regardless of mode, with the Metropolitan Transportation Authority's (MTA) transit router calculating a distance of 10.5 miles, and MapQuest calculating an auto trip distance of 9.2 miles (distance minimized) or 13.0 miles via nearby freeways (travel time minimized).

Those who reported traveling that day by different modes also showed substantially different estimates of the distance to City Hall (see Table 1), with the difference in mean estimated distance from the survey site to Los Angeles City Hall between auto users and public transit users significant at the 0.95 level. Those who drove or walked the day of the survey (N=40) reported the smallest mean distance, approximately 11 miles. Public transit users (N=21) reported a much larger mean distance, 17.3 miles, and auto passengers (N=13) an even larger mean distance, of 26.1 miles – more than 2.5 times the most direct auto or transit travel distance. The estimate of drivers and walkers was the most accurate, between the two MapQuest calculations of travel distance. Transit users' mean accuracy is worse than those two groups, with auto passengers even worse. Furthermore, the inaccuracies of transit users and auto passengers trend toward greater distances.

TABLE 1 Distance Estimated from Survey Site to Los Angeles City Hall, Grouped by Travel Mode

Mode	*Mean Distance*	*Standard Deviation*	*N*
Public Transit	17.3	15.6	21
Auto Driver	11.2	7.3	23
Auto Passenger	26.1	43.9	13
Walking	11.1	13.7	17
Other	11.8	2.4	4
Total	15.3	21.7	78

The results are consistent with our hypotheses of how the most frequently-used travel mode influences cognitive mapping. Driving and walking are both "active" modes, in which travelers must be more or less constantly processing spatial cues as they travel, resulting in more accurate cognitive maps. Auto passengers are more likely to be cognitively inactive during travel, with the predictable result that their cognitive maps are decidedly inaccurate, with destinations seeming farther away than they actually are. Transit users occupy a middle ground, active periodically, at nodes such as the origin, transfer points, and destination, but much more passive en-route. If auto drivers and transit users were the only groups compared, it would be possible to argue that the longer distance estimated by transit users could be due to longer travel times experienced by transit users. This type of overestimation is a different cognitive effect. However, the sample includes auto passengers' distance estimates, and their estimates are even longer than those of transit users, even though they should experience similar travel times to those of auto drivers. Therefore, we can conclude that the travel time effect, if present, is minimal or functioning in concert with the effect of mode itself.

The standard deviations of the estimated distances between the shopping center and Los Angeles City Hall also merit consideration. Putting aside the small "other" group, auto drivers have the lowest standard deviation in their estimates. The standard deviations of public transit users and auto passengers are larger, and by an even greater scale than the mean differences. This suggests that not only does average distance increase, but uncertainty about distance as well. It should be noted that while walkers had a rather accurate estimate of mean distance, the standard deviation of their estimates is closer to that of public transit users.

We hypothesize that the effects of travel mode influence the cognitive map over a lifespan of travel and wayfinding experiences. Therefore, the survey includes multiple measures of mode, indicators of short-, medium-, and long-term modal prevalence. Although mode traveled to the survey site is a short term measure, we also asked respondents about the availability of autos in their household. Auto availability measures modal prevalence over the longer term but is less precise in terms of specific modes utilized. Notwithstanding these differences, the variation in the distance estimation task among groups defined by auto availability is quite similar to the variation observed among the modally-defined groups.

Table 2 describes mean estimated distance from the survey site to Los Angeles City Hall by auto availability. Those reporting an auto as "always" (N=32) available were the most accurate, and those reporting "never" (N=18) were the least accurate, with the difference in mean estimated distance from the survey site to Los Angeles City Hall between those indicating an auto is "always" available and those indicating "never" statistically significant at the 0.95 level. The middle choices, "usually" (N=8) and "sometimes," (N=19) were slightly flipped relative to the hypothetical result, but their greater similarity in meaning and the small size of the "usually" group, suggests that they may be best interpreted collectively, with an estimate right between the "always" and "never" groups. The similarities between distance estimates by mode or by auto availability are striking, the trend evident both by mean and standard deviation. (As would be expected, a relationship was found between individuals' responses to questions about mode taken that day and auto availability. Ninety-three percent of auto drivers reported having an auto always or usually available. Conversely, only 27 percent of public transit users reported having an auto always or usually available, and 30 percent of auto passengers reported the same. Walkers, however, had a more mixed result, with only a slight minority (42 percent) reporting having an auto always or usually available.)

TABLE 2 Distance Estimated from Survey Site to Los Angeles City Hall, Group by Auto Availability

Auto Available	*Mean Distance*	*Standard Deviation*	*N*
Always	10.1	6.9	32
Usually	17.0	18.0	8
Sometimes	14.3	12.8	19
Never	24.6	38.6	18

3.2.3 Configurational Knowledge and Travel Mode

Distance estimation questions can be used to investigate the detail and accuracy of routes in a cognitive map. As the literature review suggests, however, cognitive maps vary across individuals by more than the quality (e.g. detail and accuracy) of individual routes. Cognitive mapping of destinations and the means to access them can be characterized by stages of development, referred to in the literature as "landmark," "route," and "configurational" (or "survey") knowledge. Landmark knowledge is the least refined stage of spatial knowledge, in that destinations are only tentatively attached to transport network, and are accessible only by navigating from landmark to landmark. Route knowledge is the next phase, wherein destinations are tied to specific, known routes, though these routes are not necessarily linked to one another or to a broader transportation network. The most advanced stage is configurational knowledge, wherein separate routes have coalesced into a fully functioning "map" of the environment, allowing an individual to evaluate and choose alternatives when navigating to known and, importantly, to new or unknown destinations.

In order to test the level of refinement of individuals' cognitive maps, we asked respondents to describe the location of their home in an open-ended way, allowing them to name a wide variety of potential cognitive map components to pinpoint their residence. Indeed, respondents use a variety of spatial information in reporting their home location: streets, cross streets, landmarks, and ZIP codes. Table 3 describes the frequency with which each modal group (defined by the principal transport mode they used that day) invoked the various types of spatial information. We can see that each spatial type appears to be suited to a particular mode. In general, most respondents chose to describe the location of their home with a street name. Walkers were especially likely (95%) to locate their home by street name, and relatively less likely (47%) to name a cross street. Auto drivers, by contrast, were somewhat less likely to offer a street name (80%) and a bit more likely to list a cross street (57%). While less common among all types of travelers, auto passengers were most likely to identify their home location by a landmark (29%, compared to just 10% among walkers), and public transit users were more than three times as likely as auto drivers (23% to 7%) to locate their home by ZIP code.

TABLE 3 Comparing Travel Mode and the Quality of Cognitive Knowledge

	Describes Location of Home By			
Mode	*Street*	*Cross Street*	*Landmark*	*ZIP Code*
Public Transit	80%	47%	20%	23%
Auto Driver	85%	57%	18%	7%
Auto Passenger	79%	50%	29%	14%
Walk	95%	47%	10%	16%

Note: Frequencies of spatial descriptors will add up to more than 100 percent for each mode as most individuals used more than one type of spatial descriptor.

These differences suggest that there are qualitative differences in how individuals using different modes construct their cognitive maps. Knowledge of cross-streets, for example, may indicate a more full fledged, configurational understanding of the transport network, while reliance on landmarks could be an indicator of the less refined, landmark phase of cognitive map development. The use of ZIP codes may indicate a different type of knowledge altogether, where cognitively aspatial designations supersede spatial knowledge. As highlighted in Table 3, for most individuals, the cognitive map is likely to be a complex mixture of all types of knowledge. Nevertheless, the group differences in spatial information by mode do suggest that travel mode plays some role in this process of cognitive development.

The modal distinctions by which respondents identified their job locations were even more pronounced than for home locations. Table 4 shows the frequency with which respondents described the location of their home and their employment using cross streets, by mode. As with home location, auto drivers were the most likely (46%) to use a cross street to locate their occupation. However, travelers by other modes on the survey day were far less likely (public transit 31%, walker 20%, and auto passenger 16%) to refer to their work location by cross streets, generally matching the patterns observed in our distance estimation exercise. Unlike the distance estimation measure, walkers' responses were more similar to auto passengers, rather than auto drivers. Modal differences in the reference to cross streets may be more pronounced for job location because home locations are so very familiar to all respondents, regardless of travel mode.

TABLE 4 Knowledge of Cross Streets for Home and Employment Location by Travel Mode

	Describes Location with Cross Streets	
Mode	*Home*	*Employment*
Public Transit	47%	31%
Auto Driver	57%	46%
Auto Passenger	50%	16%
Walk	47%	20%

4. CONCLUSION

A few scholars have previously suggested the importance of cognitive mapping to travel choice models (*3, 4*). Much of this literature has focused on the role of spatial cognition in predicting travel paths. We have tried in this paper to take the application of cognitive mapping to travel behavior analysis a step further by arguing that the links between cognitive maps and travel choices are central to understanding many aspects of travel behavior beyond route choice. While the relatively abstract and difficult-to-measure qualities of cognitive maps pose an application challenge to transportation planners, it's not an insurmountable one in our view.

Activity-based modeling could be enhanced significantly with better information on how modal experience shapes individuals' cognitive maps. The literature on household activity modeling as a more conceptually sound and robust way to predict travel behavior than traditional travel demand modeling is large and growing (*25-28*). The research reported here suggests that the cognitive maps of people who mostly walk and use public transit may vary systematically from those who are mostly chauffeured in private vehicles, and from those who usually drive. Past modal experience may substantially affect future trip generation and trip distribution. As land use/travel patterns are disaggregated in new activity-based models, cognitive mapping data can be incorporated to modify land use patterns, transportation linkages, and destination values for individuals, households, or groups. Integration of such data could resemble the implementation of refined microeconomic travel decision-making in activity-based land use and transportation models (*29*). Cognitive mapping can inform how individuals incorporate and value places and pathways in a regional system, modifying utility maximization problems of both residential location and travel behavior.

The outcomes observed in this analysis are consistent with research on job search behavior among low-wage workers. Those with regular access to private vehicles tend to search larger geographic areas for work, and to perceive job opportunities in less spatially constrained ways (*30, 31*). To remedy such cognitive barriers to job opportunities experienced by those without regular access to autos, "compensatory" solutions such as trip-planning services, guaranteed ride home services, and overall improvements to transit service could be implemented. Increasing access to electronic mapping tools among lower-income households could also compensate for limitations in individuals' cognitive maps. Such systems – like Google Maps, MapQuest, and the like – reduce individuals' reliance on their own cognitive maps, potentially increasing access to job opportunities in unfamiliar locations.

Transit planning could potentially benefit from cognitive mapping research. First, transit information could be represented diversely, with landmarks and iconic representations of major destinations for those with only rudimentary spatial knowledge, separate representations of individual routes for those with route knowledge, and with transit networks overlaid on detailed maps of street networks for those with advanced configurational knowledge of the city. Second, if street and transit networks tend to be constructed separately in the minds of most travelers despite the fact that they overlap in space, this may explain why large shares of private vehicle drivers never use, or even consider using, transit. While they likely prefer private vehicle travel over transit in most cases, if transit networks are effectively transparent most drivers may never consider using transit – even when in cases where an auto is not available for particular trips to congested destinations with expensive parking where transit may be competitive with autos. Accordingly, marketing programs could be targeted to integrate transit networks into the cognitive maps of drivers, encouraging drivers to amend their cognitive maps to include transit as a possibility for some trips.

We conclude that cognitive mapping research has potential to address the emerging focus on accessibility in transportation research. While accessibility has traditionally been conceived as the impedance people face in availing themselves of activities, cognitive mapping research shows that physical distance is but one factor defining this impedance and, in turn, the spatial choices of travelers (*32*). Our survey findings suggest that cognitive mapping is indeed influenced by travel mode experience. In general, "active" travelers – drivers and walkers – appear to have systematically different cognitive maps than more "passive" travelers on public transit and, especially, passengers in cars. Such modally-constructed cognitive maps reflect perceptions of opportunities, and hence functional accessibility, in ways that travel behavior researchers are only beginning to understand. To a carless job seeker, job opportunities not easily reached by transit are effectively out of reach, and even transparent, regardless of Euclidian distance. Modally-constructed cognitive maps, in other words, are key to understanding both travel behavior and accessibility in cities.

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