Research Council, Washington, D.C., Jan. 1980, pp. 115-147.
7. D. Oeding. Verkehrsbelastung und Dimensionierung von Gehwegen und anderen Anlagen des Fussgaengerverkehrs. Strassenbau und Strassenverkehrstechnik, No. 22, 1963.
8. B. Pushkarev and J. M. Zupan. Capacity of Walkways. In Transportation Research Record 538, TRB, National Research Council, Washington, D.C., 1975, pp. 1-15.

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Walking Straight Home from School: Pedestrian Route Choice by Young Children

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ABSTRACT

Unobtrusive observations of 50 randomly selected pedestrian youngsters were made after the children had been dismissed from elementary schools in Lincoln, Nebraska. The results demonstrate that (a) 88 percent of the students walked directly to a residential dwelling; (b) 98 percent chose a least-distance path from their school to their residence or other destination; (c) the majority of students (62 percent), by choosing to minimize distance, found their route choices reduced to a single route option; and (d) when faced with the choice between two or more distance-minimizing routes, the children in this study selected structurally more complex routes than did adults. All the children in this study were among the first students to leave school after class and walked home unaccompanied. The children appear to follow the admonition to come straight home from school, but in so doing they are generally limited to a single shortest-distance option. Such children thus have a much constrained opportunity for environmental exploration. When faced with the chance to choose a more interesting and spatially complex route while still adhering to the norm to come straight home, the complex route was generally selected. Because of the small sample size in this study, these findings are best considered suggestive rather than definitive.

Young children in the United States are frequently directed by their parents to come straight home from school. Whether this admonition is generally heeded as well as questions about trip length, walking velocity, and route complexity form the central focus of this study. An empirical investigation of the pedestrian routes selected by youngsters after they are dismissed from elementary school is reported here. A random sample of grade-school students from public schools was unobtrusively tracked and their routes were mapped in order to gather the data required for this study. The sections below provide a description of the methodology employed and a discussion of the results obtained. First, however, it is noted that choosing a route involves somewhat more than just the ability to place one foot in front of the other.

PEDESTRIAN SKILLS IN CHILDREN

Selecting a route that leads from school to home represents a high degree of pedestrian skill. This skill builds on the ability to walk per se as well as on development of sufficient risk-assessment capability to cross streets without being struck by motor vehicles. In addition, each youngster learns a subtle set of social norms (for example, which side to step to in order to avoid collision with another pedestrian, how to look at other pedestrians without appearing to stare at them, what minimum distance to maintain when following another pedestrian, and so on) that facilitate walking in its social context. Finally, the pedestrian navigator also requires knowledge of his or her spatial environment and the ability to utilize this information to choose and follow a route (1).

The age at which these interrelated skills are adequately developed and integrated is not known at this time with certainty. It is likely that development is influenced by culture, social class, and the texture of the physical environment. Routledge et al. (2) found that school children can provide reliable estimates of their exposure to risk during the journey to and from school. Reiss (3) suggests that school children can be quite verbal about their reasons for following a particular route, for example, that it is the shortest or safest way. He concludes his paper with the following observation (3, p.43): "The pattern of responses shows a progression of pedestrian capability from kindergarteners to the eigth graders."

A decade ago, Wolff (4) found that adult pedestrians often treat children under 7 years old as baggage. He suggested that we might profitably ask (4, p.45):

> At what age or stage of development have children learned to negotiate right-of-way, territorial possession, and so forth, in public places? At what age or under what conditions is their attempted use of such knowledge "respected"?

Routledge, Reiss, Wolff, and others provide starting points for further investigation related not only to pedestrian safety and transportation research but also to our increasing understanding of human perception and cognition, environmental utilization, and spatial experience. In any event, it appears that the required pedestrian skills are developed early in most youngsters to the extent that many parents permit their children to walk home from school unaccompanied.

The young, capable pedestrian now stands in front of his or her school building, choosing a route homeward that fulfills his or her parents' mandate to come straight home from school. In some instances, if the chosen route is the shortest possible one, there will be only one possible route to follow. There will be, statistically speaking, no degrees of freedom given the geometry of the street network and the constraint to minimize distance. In many other cases, however, depending on the geometry of the street network, there may be several routes, which all minimize distance. This latter situation occurs frequently when one must move diagonally across a rectangular or Manhattan street grid. In graph theoretic terms, the route selection problem involves choosing a set of connected edges from those available in a given graph to form a path from an origin to a destination. Further discussion and illustration of this terminology and descriptive framework is found in the work of Garbrecht (5,6) and Hill (7-9). The character of the route networks faced by school children in particular is discussed more fully below. First, however, the following section describes the sampling and observational methodology employed to empirically study the paths selected by school-age children on their way home after classes.

METHODOLOGY

Lincoln, Nebraska, was selected for the study. This city provides a diverse urban environment of moderate size (approximately 180,000 population). There are 27 public elementary schools within the study region and 10 were randomly selected as observation sites. All schools selected conducted afternoon classes in kindergarten through sixth grade. Enrollments ranged from a high of 700 students to a low of 168 students. The mean number of students was 418 per school.

Fifty observations (five at each school) were made of the routes selected by grade-school children as they walked home from school during the spring months (March-May). Observation began at afternoon class dismissal time when the first student crossed through the street intersection nearest the main entrance to the school. This student was unobtrusively tracked on foot and his or her path was recorded on a prepared data-collection form. Route data were recorded only for children who walked home unaccompanied. Research on the paths selected by groups of children remains to be done in the future as does research on children other than the first ones to leave the school building each day.

When a student entered a building and remained there for a period of 10 min, the observation was terminated and the child was recorded as having reached a destination. No student was included more than once in the sample. Following data collection, each observation was mapped on a standardized record sheet at the scale of 1:8,000. All data were then summarized for each case and entered for machine storage and processing. After each observation, the school for the next day's observation was determined by random choice.

Only one observation could be completed per day. Thus, this technique required more than 50 trips to the selected schools and approximately 3 months to complete. The data are therefore time-consuming to collect, so methodologically speaking, they are fairly expensive.

Reactivity of the method was judged to be minimal. Two observations were discontinued (and the data thrown out) when the researcher felt that he may have been spotted by the children under observation. With practice, it is possible to make observations from as much as two blocks away and from the side of the street opposite that on which the subject is walking. It is recommended that the observer wear comfortable shoes and be in relatively good physical condition so that he or she can catch up quickly when the subject rounds a street corner and thereby escapes the observer's direct line of vision. To further reduce reactivity, an observation should, as a rule, be discarded if the subject turns and looks in the direction of the observer more than one time during the course of the observation. Although used in other studies (9), this rule never received an opportunity for application in this study. Finally, a surprisingly large number of adults (many in automobiles) waited near the schools each day to pick up their children. As a result, the presence of the researcher at class dismissal time was not particularly conspicuous or unusual.

RESULTS

The basic characteristics of the sample are straightforward. Nineteen subjects (38 percent) were boys and 31 (62 percent) were girls. The shortest trip observed was 0.10 km and the longest was 1.34 km. Mean length of observed trips was 0.58 km. Mean trip length was essentially identical for both sexes. This result should occur in a random sample, especially if it is assumed that all students, regardless of sex, generally go straight home and it is further assumed that the homes of both male and female students are randomly located around the elementary school. Insofar as the majority of trips (88 percent) terminated at residential dwellings, it seems reasonable to assume that most unaccompanied youngsters, at least those who are among the first to leave the school building each day, go directly home after school.

Boys were observed traveling at slightly higher velocities, on average, than girls, but the difference is not statistically significant. As a group, the observed school children traveled faster (102 m/min) than a random sample of 21 subjects from the general population aged 5 to 21 years observed in a companion study (9), who on average logged only 87 m/min. This difference is statistically significant at the 0.01 level. It appears that some children in fact run rather than walk home from school.

Distance Minimization in Route Choice

With only one exception, every trip observed followed a shortest-distance path from start to finish. This finding demonstrates the overwhelming importance of distance minimization in path selection. This finding is expected given the frequently observed human tendency to minimize effort (10,11). Hill (9) has shown that the same behavior occurs in adults as well. Because no students became lost, a condition that would be indicated by longer-than-necessary routes, this finding further suggests that the subjects knew their routes and destinations well. Because subjects were not interviewed, however, it is not known if the observed route choices were prescribed by parents or teachers or were learned through experience or by watching other children or siblings. Nonetheless, in the sense that the observed students almost universally took the shortest paths to their destinations, it is clear that these students did come straight home when, in fact, home (as indicated by a residential dwelling) was their intended destination.

When distance minimization is employed as a primary route-selection strategy, however, the number of available routes is often reduced dramatically. In other words, if one is not willing to walk further than necessary, one cannot then select from many other, but more roundabout, routes. In the case of the school children observed in this study, 31 students (62 percent) had no choice but to take the route they did if they wished to minimize distance. The remaining 19 students (38 percent) had the option of choosing from two or more different routes that minimized the distance to their destinations.

It should be noted further that students who tend to live closer to school (0.5 km on average) have no option in route choice except for a single, distance-minimizing route, whereas those who live farther away (0.8 km on average) get to choose from more than one distance-minimizing option. This result stems in part from the interacting dimensions of trip length and street geometry. Generally, the greater the distance a student lives from an elementary school, the higher the probability that more route options will be available (9). The important point is that the street geometry faced by the majority of students who actually do walk home from school is exceedingly simple, if not boring: There is frequently only one least-distance route from which to choose. Day after day, if students follow the maxim to minimize distance (and 98 percent of the students observed did so), they are often constrained by street geometry to repeat the same route choice again and again without variation.

Choosing Between Paths of Equal Length

Not all students, however, are constrained by rigid geometry and they have some degree of real choice in selecting from a variety of distance-minimizing routes. Based on the observations in this study, it is estimated that approximately 38 percent of the students have the opportunity for more varied route selection. The next stage of inquiry, therefore, is to ask how children behave when they experience the problem of choosing between two or more distance-minimizing routes of equal length. Such routes can be compared on the dimension of structural complexity.

An important aspect of route structure is the complexity of the route. Conceptually, environmental complexity is best approached with the subtlety and keen theoretical edge demonstrated by Rapoport and Hawkes (12) and Rapoport (13,14). In this study, however, a simple but readily quantifiable measure of structural complexity is employed as a rough substitute. Here the complexity of a route depends on the number of turns (or changes of direction) that a subject is free to incorporate into his or her path from one point to another. The spatial structure index (SSI) is a measure that allows objective comparison of route complexity for paths followed in street networks of radically different size and configuration. Further, the parametric properties of the SSI ultimately permit the analysis of route complexity as a function of other variables. In brief, the index is a standardized measure of the number of turns incorporated in a given distance-minimizing trip relative to the maximum and minimum number of turns that could have been taken by the pedestrian. The index is based on an adaptation of the formula for computing standardized scores (Z-scores). The computation and limitations of the index, together with examples, have been illustrated by Hill (9).

Computational limitations are such that the SSI could be computed meaningfully for only 12 children in the sample. Given this small sample size, the SSI results reported here must be seen as indicative rather than definitive. Although larger samples are undoubtedly desirable, they are time-consuming and difficult to obtain. Hill (9) has demonstrated that route selection by adults can be studied adequately through survey questionnaire techniques, but it is not known whether grade school children can be depended on to adequately and reliably describe their exact walking routes on a questionnaire. If such techniques (or alternatives such as video simulations) could be perfected, much larger samples would be obtained with considerably greater ease.

The SSI has a maximum value of 0.7071, a mean of 0.0, and a minimum value of -0.7071 regardless of the size or shape of the street network involved. A value of -0.7071 results when a trip with the least number of turns possible has been chosen. Conversely, a positive value of 0.7071 is found when a trip with the maximum number of turns has been selected. Following the lead of Rapoport and Hawkes (12), a route with the most possible turns is operationally defined as the structurally most complex route. It is in this sense that the SSI is said to reflect the structural complexity of a given trip.

Using the SSI, it was found that children walking home from school tend to exhibit more complex path structures than do adults generally. Recalling that a positive SSI value reflects relatively complex route choice, it is noted that the mean SSI for 12 school children (-0.059) is more positive than the SSI for a random sample of 24 distance-minimizing adults (-0.275) who were unobtrusively tracked within the same study area in a companion investigation (9). This difference is statistically significant at the 0.01 level.

This result is expected, based on Perin's discussion (15) of White's thesis of effectance, in which it is maintained that increased exploration of the environment is integral to human maturation. In capsule form, this thesis asserts that environmental manipulation (in this case choosing more complex route structures) is important during an individual's development if that person is going to develop an adequate sense of personal competence. The developed adult, therefore, would no longer need to engage in environmental manipulation to the extent required for developing youngsters. In addition to the development of a sense of personal competence, Piaget and Inhelder (16) maintain that environmental exploration is required in order for youngsters to develop a sense of space. Finally, Merleau-Ponty (17) observes that physical movement and use of the environment are required for children to establish a stable orientation in the physical world. Thus, it is expected that young school children will, given the opportunity for more complex choices, be exploratory in their route selection because they are still learning how to navigate and master the built environment in which they live.

Although the data collected in this study are the result of relatively expensive methodological techniques, it is hoped that additional work will pursue the questions that this project only began to address. Such studies, if taken in small steps, are fully within the capabilities and thesis expectations of graduate students in planning, engineering, and the social sciences. Like the many small-scale studies on the spatial aspects of human crowding (18), such investigations not only provide insights for more robust theoretical explanations of environmentally situated behavior (19) of which pedestrian behavior is a paradigm example, they also add to our growing stock of research and insight on the nature of the pedestrian experience (1,20-24).

SUMMARY

The results and methodology in this study are more fully reported elsewhere (9), but the basic findings are straightforward. In regions similar to the study site, it is expected that unaccompanied school children (at least those who are among the first to leave their school building each day) are almost universally likely to take the shortest route home from school and, when confronted with the opportunity to choose between two or more shortest-distance routes, to frequently select a structurally more complex route. By and large, however, the majority of children are presented with only a single shortest-distance option as the route to their home. On the way home from school, at least, these children have a much constrained opportunity for environmental exploration in a spatial structural sense.

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REFERENCES

1. M.R. Hill. Walking, Crossing Streets, and Choosing Pedestrian Routes: A Survey of Recent Insights from the Social/Behavioral Sciences. Nebraska Studies Monograph Series. University of Nebraska, Lincoln, in press.
2. D.A. Routledge, R. Repetto-Wright, and C.I. Howarth. The Exposure of Young Children to Accident Risk as Pedestrians. Ergonomics, Vol. 17, 1974, pp. 457-480.
3. M.L. Reiss. Young Pedestrian Behavior. Transportation Engineering, Vol. 47, No. 10, 1977, pp. 40-44.
4. M. Wolff. Notes on the Behavior of Pedestrians. In People in Places: The Sociology of the Familiar (A. Birenbaum and E. Sagarin, eds.), New York, Praeger, 1973, pp. 35-48.
5. D. Garbrecht. The Binomial Model of Pedestrian Flows. Traffic Quarterly, Vol. 23, 1969, pp. 587-595.
6. D. Garbrecht. Pedestrian Paths Through a Uniform Environment. Town Planning Review, Vol. 41, 1971, pp. 71-84.
7. M.R. Hill. Pedestrian Behavior in an Urban Environment. Department of Geography, University of Nebraska-Lincoln, 1975.
8. M.R. Hill. Pedestrians, Priorities, and Spatial Games. In Priorities for Environmental Design Research (S. Weidemann and J.R. Anderson, eds.), Environmental Design Research Association, Washington, D.C., 1978, pp. 126-136.
9. M.R. Hill. Spatial Structure and Decision-Making Aspects of Pedestrian Route Selection Through an Urban Environment. Ph.D dissertation. University of Nebraska-Lincoln, 1982.
10. M.R. Hill. Spatial Propinquity as an Applied Concept in Environmental Research and Design. In The Behavioral Basis of Design (P. Suedfeld and J.A. Russell, eds.), Hutchinson Ross, Stroudsburg, Pa., 1976, Vol. 1, pp. 63-68.
11. G.K. Zipf. Human Behavior and the Principle of Least Effort. Addison-Wesley, Reading, Pa., 1949.
12. A. Rapoport and R. Hawkes. The Perception of Urban Complexity. Journal of the American Institute of Planners, Vol. 36, No. 2, 1970, pp. 106-111.
13. A. Rapoport. Human Aspects of Urban Form: Towards a Man-Environment Approach to Urban Form and Design. Pergamon Press, Oxford, England, 1977.
14. A. Rapoport. On the Perceptual Separation of Pedestrians and Motorists. In Road Safety: Research and Practice (H.C. Foot, A.J. Chapman, and F.M. Wade, eds.), Praeger, London, 1981, pp. 161-167.
15. C. Perin. With Man in Mind: An Interdisciplinary Prospectus for Environmental Design. MIT Press, Cambridge, Mass., 1970.
16. J. Piaget and B. Inhelder. The Child's Conception of Space. Routledge and Kegan Paul, London, 1956.
17. M. Merleau-Ponty. The Phenomenology of Perception. Humanities Press, New York, 1963.
18. M.R. Hill. Space and the Experimental Study of Human Crowding. Great Plains--Rocky Mountain Geographical Journal, Vol. 6, No. 2, 1977, pp. 246-254.
19. M.R. Hill. Misunderstanding the Goals of Science: Myths, Reconciliation, and an Example. In Environmental Design Research, Theory and Application (A.D. Seidel and S. Danford, eds.), Environmental Design Research Association, Washington, D.C., 1979, pp. 248-255.
20. D. Garbrecht. Pedestrian Movement: A Bibliography. Exchange Bibliography 225. Council of Planning Librarians, Chicago, Ill., 1971.
21. M.R. Hill. Pedestrian Behavior and Facilities Design: Selected Bibliography 1970-1975. Exchange Bibliography 1112. Council of Planning Librarians, Chicago, Ill., 1976.
22. D. Garbrecht. Gehen: Pladoyer fur das Leven in der Stadt. Beltz Verlag, Weinheim, West Germany, 1981.

23. M.R. Hill. Man-Environment Studies, Vol. 11, Nos. 1 and 2, 1981.
24. M.R. Hill. Recent Social/Behavioral Science Contributions to Our Understanding of the Pedestrian Experience: A Brief Review. In Feet Accompli: Linking People with Places, Proc., Third Annual Pedestrian Conference, Boulder, Colo., 1982.

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Role of Bicycles in Public Transportation Access

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ABSTRACT

Bicycles play a vital role in access and egress for rail and express bus services in Japan and northwestern Europe as well as in a growing number of communities in the United States. Suburbanization has been a driving force for the growth of bicycle-transit linkage. In many suburban towns in Japan, West Germany, Denmark, and the Netherlands, 25 to 50 percent of rail station access trips and up to 20 percent of station egress trips are made by bicycle. The number of trips involving a combination of bicycles and public transportation has quadrupled in Japan and doubled in Denmark since the early 1970s. In the United States, high bicycle theft rates have restrained similar growth except for transit systems that have made special provisions for bicycle access. Significant use of bicycles for transit access is found only where bicycle theft rates are relatively low or where secure bicycle parking has been provided at transit stops. The evolution of transit access systems is discussed and park-and-ride versus bike-and-ride transit access are compared with regard to capital and operating costs, air pollution and energy use, impacts on transit ridership, implications for transit stop siting, and other factors. It is concluded that American transit agencies could substantially increase suburban transit use without increased operating costs by improving bicycle-transit integration. Bike-and-ride development is far more cost-effective than park-and-ride development.

This study arose out of research begun at Public Technology, Inc., the technical arm of the National League of Cities. A search for information about bicycle-transit linkage revealed that little information has been available on the experiences of American transit agencies. Even less information has been available in English regarding the role of bicycles as an access and egress mode to public transportation in other mature industrialized societies. Although the number of U.S. transit operators initiating bicycle-transit linkage programs has been growing, no body of information has existed to guide these efforts.

The collection of both descriptive and analytical data on bicycle-transit linkage was carried out through the course of 8 months of research, site visits, and meetings with transit agency and government officials, businessmen, and citizen activist leaders in Japan, the Netherlands, West Germany, and Denmark. Additional research was conducted over a 2-year period in the United States.

A more extensive presentation of the research findings is contained in a recently released book, Bicycles and Public Transportation: New Links to Suburban Transit Markets, published by the Bicycle Federation, Washington, D.C. (1).

BACKGROUND

The traditional market base for public transportation has been eroded by the shift of population and employment growth from dense urban centers to suburbs and small cities. Although transit agencies have expanded their routes and services into these new areas of growth, it has become ever more difficult to provide cost-effective public transportation within walking distance of the places to which people want to go. Suburban growth has far outpaced the development of suburban transit services.

Suburbanization and deurbanization have not been confined to the United States but are common trends in Japan and Europe as well. By 1980 one-third of all Western European cities with more than 200,000 residents were losing population (2). Between 1960 and 1971, all major Dutch metropolitan areas showed significantly faster rates of employment growth in suburban areas than in their urban cores, with a decrease in absolute employment in two out of seven metropolitan regions (2). Similarly, the fastest rates of population and employment growth in Japan are in the areas at the fringe of metropolitan regions, whereas the population of major urban cores has been declining since the mid-1960s (3).

With more people living at greater distances from transit routes than at any time in the past century, the mainstay of transit access and egress, walking, is being replaced increasingly by other access and