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Active transportation and physical activity: opportunities for collaboration on transportation and public health research

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Abstract

Physically inactive lifestyles are a major public health challenge, and research in the transportation field on influences on the choice to walk and bike may provide guidance toward solutions. In the interests of promoting effective collaboration among the transportation, planning, and health fields, the current paper was written to fulfill three purposes. The first purpose was to summarize the transportation and planning studies on the relation between community design and non-motorized (''active'') transport and to interpret these studies from a health perspective. The second purpose was to summarize studies from the health literature that examine the relation between physical environmental variables and leisure-time physical activity that have relevance for transportation research. The third purpose was to promote more collaboration among transportation, planning, and health investigators by identifying opportunities for transdisciplinary research.

1. Overlapping agendas: physical activity and active transport

Only recently have we come to understand that physically inactive lifestyles are one of the major public health challenges of our time. The epidemiologic evidence linking physical inactivity with numerous health problems emerged mainly in the late 1970's and 1980's. By contrast, there was a large literature on the health effects of smoking by the early 1960's. Now, physical inactivity

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is a well-documented risk factor for the chronic diseases that kill most Americans, including coronary heart disease, stroke, some cancers, diabetes, and depression (US Department of Health and Human Services, USDHHS, 1996). Inactive lifestyles are responsible for about 200,000 deaths in the US each year, second only to tobacco, which kills about 400,000 (USDHHS, 1996; McGinnis and Foege, 1993). Less than 20% of adults are smokers, but more than 70% do not meet physical activity recommendations (USDHHS, 2000). Physical inactivity costs more than $77 billion per year in the United States in direct medical expenses alone (Pratt et al., 2000). Physical inactivity can be considered a public health crisis.

Low levels of energy expenditure from physical activity are believed to be partly responsible for the current overweight/obesity epidemic, though direct documentation is lacking. About 65% of US adults were overweight [body mass index or BMI (kg/m^2) >25.0] in 1999–2000, compared to about 56% in the early 1990's (Flegal et al., 2002), and more than 20% of US adults meets criteria for obesity (Mokdad et al., 2003). Recent and rapid increases in the prevalence of youth overweight also are occurring (Strauss and Pollack, 2001; Ogden et al., 2002). The multiple negative health consequences of physical inactivity, contributions to the overweight/obesity epidemic, and the large proportions of inactive Americans are leading public health officials at federal and state levels to examine closely the causes of physically inactive lifestyles and to search for solutions that can increase physical activity throughout the population, improve health, and reduce health care costs (Kahn et al., 2002; USDHHS, 1996).

Achieving physical activity levels that provide substantial health benefits is realistic for almost all adults. Current public health recommendations emphasize the benefits of accumulating 30 min of physical activity daily of at least moderate intensity (USDHHS, 1996; Pate et al., 1995). The most widely agreed-upon recommendation for youth is that they accumulate at least 60 min of moderate-to-vigorous physical activity per day (Cavill et al., 2001). The largest health benefits accrue for those who move from low to moderate amounts of physical activity; there are relatively fewer benefits of moving from moderate to high levels (Pate et al., 1995; USDHHS, 1996). The most common moderate intensity activity is brisk walking, which can be done at any age. Walking can be done for transportation, health, or leisure purposes, so transportation and health professionals are beginning to cooperate to create solutions to the challenge of physical inactivity (Frank and Engelke, 2001; Frank et al., 2003).

Health and transportation researchers have examined physical activity from different perspectives. Although health is affected by total physical activity, virtually all of the health research to date has been on leisure or recreational physical activity, of which walking is the most common form (USDHHS, 1996). Brisk walking is protective of physical health, particularly if done consistently (Wagner et al., 2001), with health effects independent of the benefits of more vigorous activity (i.e., activities traditionally considered "exercise", such as running, swimming, etc.) (Manson et al., 1999).

By contrast, transportation and urban planning researchers have been interested almost exclusively in a non-overlapping subset of physical activity; walking and cycling for utilitarian purposes, usually termed "non-motorized transport". Until recently, health and transportation researchers were unaware of each other's somewhat complementary approaches (Frank et al., 2003; Handy et al., 2002; Saelens et al., 2003). However, as health researchers have become more interested in exploring the environmental correlates of physical activity (Booth et al., 2001; Sallis et al., 1998), they have encountered studies from the transportation field.

Transportation researchers have been studying health issues for some time, but the primary concerns have been traffic-related pedestrian injuries and the various health effects of automobile-related air pollution (Litman, 2002). These are major problems. The National Highway Traffic Safety Administration (NHTSA, 2003) reports there were almost 5000 traffic-related pedestrian/cyclist deaths in 2001, or about 12% of fatalities from motor vehicle crashes. There were about 41,000 traffic-related deaths of all types in 2001. A report from Europe contains an estimate that air pollution generated from motor vehicles is responsible for more deaths than all traffic crashes (World Health Organization, European Region, 1999). Thus, if the automobile-linked deaths in the US could be roughly estimated to be 50,000 (5000 pedestrian deaths from injuries +45,000 air pollution deaths), that would still be only one-quarter of the 200,000 deaths per year in the US attributable to physical inactivity (USDHHS, 1996). Thus, physical inactivity is a far more serious public health problem, and the linkage with transportation means that health and physical activity need to become central concerns for the transportation field. There is a clear need for transportation and public health professionals to collaborate closely on research, policy, and practice that will lead to joint efforts to meet societal needs.

Transportation research already has made an impact on the physical activity field, as indicated by the US Public Health Service's inclusion of a national objective for the year 2010 of more than a 50% increase in walking trips made by adults for trips less than 1 mile (USDHHS, 2000). Health and transportation researchers have used divergent approaches to understand factors that may influence physical activity and non-motorized transport. The health field has examined mainly psychological and social variables that may be associated with an individual's behavior (Sallis and Owen, 1999), while the transportation field has focused on defining environmental variables that appear to influence behavior of entire communities (Ewing and Cervero, 2001; Handy et al., 2002). Ecological models of behavior are based on the premise that the combination of psychological, social, and environmental/policy variables is expected to best explain behavior (King et al., 1995; Sallis and Owen, 1999; Sallis and Owen, 2002). Thus, developing a transdisciplinary approach that integrates the models and methods of behavioral research in the health, transportation, and urban planning fields is expected to provide a better understanding regarding the reasons why the majority of US adults lead physically inactive lifestyles (King et al., 2002). A collaborative approach may also produce advances on issues of central concern to transportation, such as social equity, pedestrian injuries, traffic congestion, and air quality, as discussed below.

In the interests of promoting effective collaboration among the transportation, planning, and health fields, the current paper was written to fulfill three purposes. The first purpose is to summarize the transportation and planning studies on the relation between community design and non-motorized transport and to interpret these studies from a health perspective. The current paper complements a review of the same studies oriented toward introducing a health audience to relevant transportation and planning literature (Saelens et al., 2003). The second purpose is to provide a brief summary of studies from the health literature that examine the relation between environmental variables and leisure-time physical activity. The health studies may be of value to transportation researchers by introducing unfamiliar models, methods, and questions that can be applied to transportation. The third purpose of the paper is to promote more collaboration among transportation, planning, and health investigators by identifying critical research priorities that are likely to be fruitful topics for such collaborations.

Because transportation and health professionals use different terminology for similar concepts, it is useful to clarify terms. ‘‘Physical activity’’ is a broad term that refers to any form of muscular movement that produces energy expenditure (USDHHS, 1996). Various purposes or ‘‘domains’’ of physical activity have been identified, including leisure, transportation, occupational, and home-based (i.e., domestic chores, gardening). ‘‘Walking and cycling for transportation’’, ‘‘non-motorized transport’’, ‘‘human powered transport’’, and ‘‘active transport’’ have all been used to describe the same subset of physical activity for transportation. Given the linkage with the physical activity and health field, ‘‘active transport’’ may be a preferred term (Litman, 2003) and is used in this manuscript.

2. Transportation research contributes to understanding physical inactivity

To date, transportation-related data collection efforts have focused on vehicular travel. Most household travel surveys are designed to enable metropolitan planning organizations (MPOs) to update their travel demand models and allow state departments of transportation, local governments, and developers to determine where to add highway and arterial road capacity. These efforts focus largely on the performance of given links within the vehicle-based transportation network underpinned by the projected volume-to-capacity ratio per network segment resulting from increases in demand over time. This widely adopted measurement of level of service for transportation facility performance is unique to vehicular movement. The vast majority of travel data collected to date overlooks and undercounts non-motorized modes, and as a result, only a few regional travel demand models have a modal choice model or an assignment routine that accounts for non-motorized modes. Nearly all regional travel models are based on traffic analysis zones that assume trips begin and end in different zones, largely negating detail accounting for short ‘‘intra-zonal’’ trips. National data on trip length per mode reveal that most of these short trips are on foot (U.S. Department of Transportation, 2003). Although these intra-zonal walking or cycling trips may be predominantly recreational in nature, many of them require use of the road network and sidewalks, so they should be considered in transportation facility planning.

More recently, however, transportation research has become concerned with built-environmental determinants of ‘‘active transport’’ modes of travel, driven largely by the need to reduce auto-generated pollution (Frank and Engelke, 2001; Handy et al., 2002; Litman, 2003). Researchers in transportation, urban design, and city planning have long understood that neighborhood design and the way land is developed affects travel behavior (Ewing and Cervero, 2001; Frank, 2000). Two fundamental concepts of urban form that impact travel choice in general, and active transport in particular, are the proximity (land use density and mix) and connectivity (route directness) between complementary activities (e.g. work, shop, play). Proximity relates to the distance between trip origins and destinations. Connectivity characterizes the ease of moving between origins (e.g., households) and destinations (e.g., stores and employment) within the existing street and sidewalk/pathway structure (Frank, 2000). Fig. 1 provides a geographic depiction of two disparate urban settings (Frank et al., 2003). Both images are 1 square mile and have the same straight-line distance between locations A and B. The key distinction is that the street network distance on the right is 0.5 miles, a potentially walkable distance, whereas on the left, this distance is 1.2 miles.

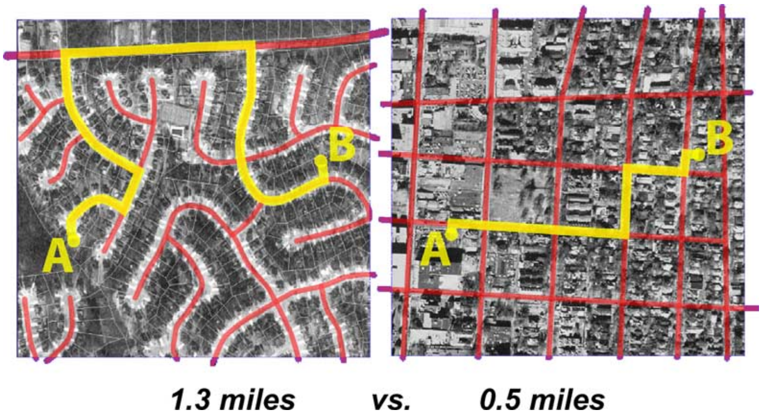

Fig. 1. Comparison of travel distances between two land use types, differing in connectivity of the street network. (Used by permission of Frank et al., 2003.)

Although the concepts of proximity and connectivity are familiar to transportation professionals, these factors also are pertinent to understanding an individual's overall level of physical activity. For instance, approximately 83% of all "trips" (each instance of moving from a point of origin to a destination) are short, for non-work purposes, and occur relatively close to home (Ross and Dunning, 1997). The majority of non-work trip destinations are within walking or cycling distance of trip origins (e.g., home) and are therefore of interest to the physical activity, air quality, and transportation planning fields. National data indicate that 14% and 27% of trips were within walkable distances of one-half and one mile, respectively, and 63% of trips were within a bikeable distance of 5 miles (Federal Highway Administration, 1994). These data indicate great potential for active transport to increase its contribution to overall physical activity. However, there are major variations in land use and travel patterns across the country, and it may be instructive to consider the potential for active transport in a region known for lack of walkability.

Travel data were collected from 8069 households in the 13 County Atlanta Region in 2000 and 2001 (www.smartraq.net). Table 1 provides detailed breakdowns of the number and proportion of trips made by distance for specific activities.

Data in Table 1 show that approximately 5% of the total reported trips were under a half-mile (walkable distance), 9% are under 1 mile, and just over 40% are less than 5 miles in distance (bikeable distance). These figures are substantially lower than the national estimates cited in the previous paragraph. As would be expected, in Atlanta a much smaller proportion of work related trips were within a walkable or bikable distance. Less than 25% of the work trips were under 5 miles in distance. Atlanta is known to have some of the longest distances to work in the US and amongst the highest vehicle miles of travel per capita in the nation. However, even in an auto oriented region such as Atlanta, 40% of trips are of a walkable or bikable distance. Trips that occur closer to home, such as eating, shopping, school, and entertainment constitute approximately 40% of all trips; a number that is collectively far greater than the 12.6% of the trips that were recorded for work. While eating and entertainment followed the average distance for all trips combined, over 8% of the shopping trips were less than a half-mile, and 53% were less than 5 miles. Five percent of the school trips were less than a half-mile and 10% were less than one mile,

Table 1
Travel distance by purpose in Atlanta

Distance in miles		Trip purpose								Total
		Eating	Entertain-ment	Work	School	Incidental shopping	Drop off/ pick up someone	Other	Do not know	
0 thru 0.25	Count	558	199	274	93	534	119	1082	0	2859
	%	2.4%	1.9%	1.9%	1.4%	4.9%	1.1%	2.7%	0.0%	2.4%
0.25 thru 0.5	Count	600	208	255	235	380	216	1073	0	2967
	%	2.5%	2.0%	1.7%	3.6%	3.5%	2.0%	2.7%	0.0%	2.5%
0.5 thru 1.0	Count	1065	417	351	322	652	473	1647	3	4930
	%	4.5%	4.0%	2.4%	5.0%	5.9%	4.3%	4.2%	8.1%	4.2%
1.0 thru 1.5	Count	1140	404	326	393	680	484	1780	0	5207
	%	4.8%	3.9%	2.2%	6.1%	6.2%	4.4%	4.5%	0.0%	4.5%
1.5 thru 2.0	Count	1012	445	375	436	568	532	1736	1	5105
	%	4.3%	4.2%	2.5%	6.8%	5.2%	4.9%	4.4%	2.7%	4.4%
2.0 thru 5.0	Count	5656	2562	2055	2204	3013	2968	9280	17	27,755
	%	24.0%	24.4%	13.9%	34.2%	27.4%	27.2%	23.4%	45.9%	23.8%
Greater than 5.0	Count	13,534	6252	11,099	2770	5161	6107	23,013	16	67952
	%	57.4%	59.6%	75.3%	42.9%	47.0%	56.0%	58.1%	43.2%	58.2%
Total	Count	23,565	10,487	14,735	6453	10,988	10,899	39,611	37	116,775
	%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Overall %	20.2%	9.0%	12.6%	5.5%	9.4%	9.3%	33.9%	0.01%	100.0%

Source: SMARTRAQ survey (www.smartraq.net).
Notes: Trips reported in Table 1 are grouped based on the activity that took place at the trip destination. Trips destined for home are subsumed under the primary activity that was to occur at home such as eating.
Trip distances were calculated based on shortest time-path network derived distances between reported trip origins and destinations taking into account facility performance for reported time of day.

indicating a limited potential for walking to school to contribute to children's daily physical activity.

These numbers suggest that even with the current land use patterns in Atlanta, where distances between destinations are vast, there is a considerable role for walking, and especially biking as viable modes of transport. However, the same travel data used in Table 1 document that driving remains the predominant mode of travel in the region, even for short distances. In fact, nearly twice as many of the trips recorded under 1 mile in distance were taken by private vehicle ($n = 6564$) as opposed to on foot ($n = 3692$).

Although there is a long history of transportation and land use planning based on health, safety, and public welfare considerations, contemporary concerns about physical activity expand on these traditions and raise new issues of relevance to transportation researchers and practitioners. Plainly stated, the hypothesis is that land uses and transportation policy and infrastructure that have been dominant since World War II favor automobile use so heavily that most people have little or no ability to walk or cycle for transportation. This appears to be an historic and dramatic shift away from millennia of experience in which walking was the major form of transport. Current reliance on personal vehicle use, along with other factors contributing to more sedentary lifestyles (e.g., application of technology to work and entertainment), has engineered physical activity for non-exercise purposes out of many Americans' lives. Most of the evidence for the hypothesis can be found in the research literature on active transport.

3. A review of research on land use and active transport

It is well established that land use affects choices about travel modes (Ewing and Cervero, 2001), but it is instructive to highlight the studies that include measures of active (typically referred to in the transportation literature as "non-motorized") transport. Studies from the transportation and urban planning research literature were identified by searching the TRANSPORT bibliographic database using terms such as "walking" and "cycling". A comprehensive review of these studies has been published in the health literature (Saelens et al., 2003), so the main findings are briefly summarized here.

One common research design compared differences in walking/cycling rates between residents of neighborhoods that differed in environmental characteristics believed related to 'walkability'. Eleven studies with this design were identified (Cervero and Gorham, 1995; Cervero and Radisch, 1996; Ewing et al., 1994; Friedman et al., 1994; Handy, 1992; Handy, 1996; Handy and Clifton, 2001; Kitamura et al., 1997; McNally and Kulkarni, 1997; Anon, 1993). Fig. 2 shows the difference in frequency of walking or cycling trips between neighborhoods purported to be more walkable (e.g., higher population density, greater mixed land use, higher connectivity) versus less walkable (e.g., low density, mostly residential land use, low connectivity). When reported as percentage of trips made by walking/cycling, weekly number of walk/bike trips was estimated, based on an assumed 30 trips weekly across all transport modes (Ross and Dunning, 1997).

The number of estimated weekly walking/biking trips reported by residents of high walkable neighborhoods was consistently higher than for low walkable neighborhood residents. Averaging across all studies and trip purposes, high walkable neighborhood residents reported approximately two times more walking trips per week than low walkable neighborhood residents

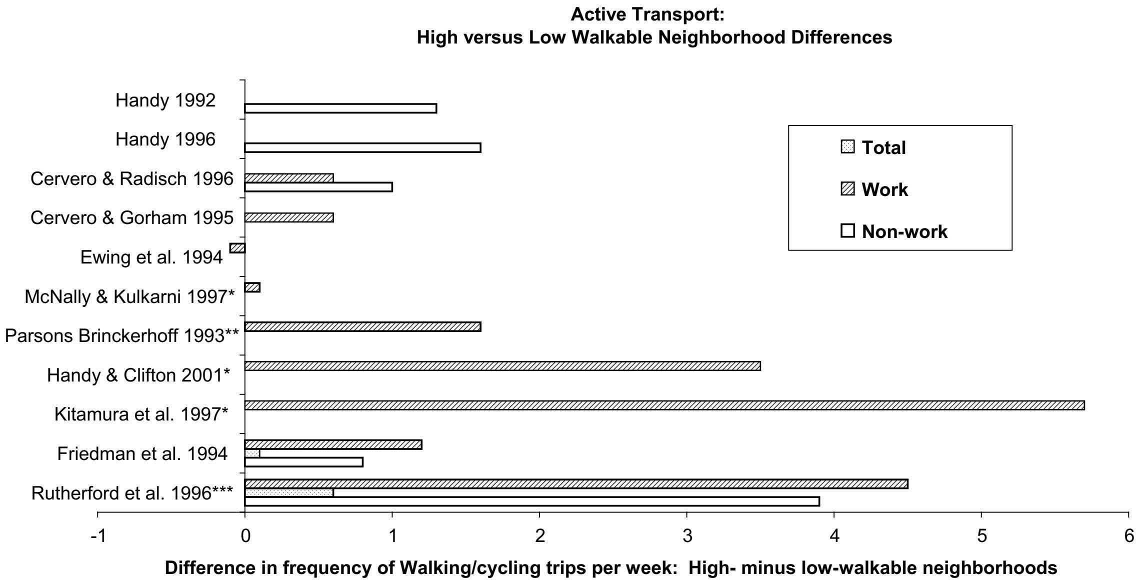

Fig. 2. Active transportation (walking and cycling) trip frequency: high-versus low-walkable neighborhood differences.

(3.1 versus 1.4 trips). Magnitude differences between high and low walkable neighborhoods (high-low) ranged from −0.1 to 5.7 walk trips, but only three of the 11 studies had differences in walking trips of less one trip per week (Cervero and Gorham, 1995; Ewing et al., 1994; McNally and Kulkarni, 1997). Handy's findings (Handy, 1992; Handy, 1996; Handy and Clifton, 2001) suggest that utilitarian trips (e.g., to go shopping or to work) were the primary source of overall differences in walking trips between high and low walkable neighborhoods, because walking for exercise did not differ between these different types of neighborhoods.

Other transportation and urban planning studies used correlational designs and multiple regression analyses to examine the magnitude of built environment associations with non-motorized transport beyond variance explained by socio-demographic variables. Neighborhood environment characteristics were related to walking and cycling for transport in virtually all of the studies. Population density was a consistent positive correlate of walking trips (Ross and Dunning, 1997; Cervero and Radisch, 1996; Anon, 1993). For example, in the 1995 Nationwide Personal Transportation Survey, travel by walking/cycling was approximately five times higher in the highest versus lowest density areas (Ross and Dunning, 1997). Land use mix, especially the close proximity of shopping, work, and other non-residential land use to housing, was related to greater walking/cycling among residents in four studies (Frank and Pivo, 1994; Hanson and Schwab, 1987; Kockelman, 1997; Cervero, 1996). Limited evidence suggested that better walking and cycling infrastructure (e.g., sidewalks and bicycle paths) was related to more walking/cycling trips (McNally and Kulkarni, 1997; Anon, 1993; Hess et al., 1999). Although not specifically examining walking/biking rates in their study, Cervero and Kockelman (1997) found that better pedestrian infrastructure, including sidewalks and street lighting, was related to greater non-automobile travel, particularly for non-work trips originating from home. Tables in the review by Saelens et al. (2003) provide additional details of the studies and findings briefly summarized here.

In summary, there is a sizeable transportation research literature that demonstrates consistent associations of neighborhood environmental variables with walking and cycling for transport. Strengths of association varied but were usually substantial. Although it can now be concluded "walkable" neighborhoods are associated with active transportation, the studies to date do not provide detailed guidance about how much of each characteristic or what combination of characteristics produce "optimal" levels of walkability. Further research is needed to provide planners and designers with more specific findings to guide practice.

From a physical activity and health perspective, the estimated mean difference between high and low walkable neighborhoods of approximately 1–2 walk trips per week conservatively translates into 1–2 km or about 15–30 min more walking per week for each resident of high walkable neighborhoods. This is roughly equivalent to residents of high walkable neighborhoods meeting the current physical activity guidelines (Pate et al., 1995) one additional day per week. In contrast to promotional programs that could potentially have greater effects on physical activity that would decay over time, the impact of living in a walkable neighborhood can be expected to last as long as the person remains a resident of that neighborhood. Maintaining increases in physical activity has been identified as one of the greatest challenges for behavior change interventions (Orleans, 2000), so environmental changes may be essential for creating long-term increases in active transport and physical activity. Especially in the current context of little or no apparent increase in adult leisure-time physical activity during the 1990s (USDHHS, 2000), the potential to enhance physical activity in entire communities by 15–30 min per week on a permanent basis should be taken seriously by public health officials and can be expected to stimulate new collaborations between public health and transportation professionals.

4. Physical activity studies can inform transportation research

In the physical activity and public health literature, many studies have examined how psychological and social variables are associated with physical activity, but few studies have explored physical environmental correlates (Sallis and Owen, 1999). Humpel et al. (2002) reviewed 16 studies that examined environmental correlates of adult recreational physical activity and concluded that access to recreational facilities and programs, as well as aesthetic qualities of neighborhoods (such as enjoyable scenery) were related to physical activity. There was less evidence of a relationship with perceived safety. Some of these correlates are relevant to transportation researchers. Some "recreational" facilities, such as bike lanes and trails, can also be used for transportation to destinations, but the extent of such use is unknown. Examination of only recreational walking and bicycling may underestimate the societal benefits of these facilities. Transportation researchers also could investigate whether neighborhood aesthetics and perceived safety are related to active transport.

Availability of recreational facilities near homes appears to be related to adults' physical activity. The self-reported presence of convenient physical activity facilities has been associated with exercise in adults (Sallis et al., 1989), has predicted increases in walking over time without intervention (Hovell et al., 1992), and has predicted adoption of vigorous exercise for men (Sallis et al., 1992a). An objective measure of density of exercise facilities around participants' homes was positively related to exercise levels, even after adjustment for age, sex, and education level (Sallis

Table 2
Studies examining the relation between active commuting and health outcomes

Ref.	Study location (sample)	Measure of commuting	Active commuting	Relation with health outcome	Covariates or other variables in models
Hu et al., 2001	Tianjin, China ($N = 3708$ men and women 20–49 y.o.)	Self-report type (walk, bike, bus) & daily duration	>90% of men, >80% of women	1. Lower total cholesterol, LDL, and triglycerides among any level of walk/bike commuting relative to bus commuting among men 2. Lower likelihood of being in highest quartile for total cholesterol and LDL among most levels of walk/bike commuting relative to bus commuting among men 3. Higher mean HDL among higher amount of walk/bike commuting relative to bus commuting among women 4. No relation between leisure sport frequency and lipid measures	Age, education, smoking status, BMI, activity level of occupation
Hu et al., 2002	Same sample source as above (Ref. 1; $N = 3976$)	Self-report type (walk, bike, bus) & daily duration	91.2% of men, 96.3% of women	1. Lower BMI among all levels of males' walk/bike commuting relative to bus commuters; lower BMI among only highest level of females' walk/bike commuting (>60 min) relative to bus commuters 2. Paradoxically, highest systolic BP among males and females commuting >60 min by walk/bike	Age, education, smoking status, activity level of occupation, alcohol consumption
Hayashi et al., 1999	Osaka, Japan ($N = 6017$ men 35–63 y.o.)	Self-report of amount of time it takes to walk to work	51% 0–10 min; 39% 11–20 min; 10% $\geqslant 21$ min	1. Decreasing BMI with increasing walk to work duration 2. Decreased risk of hypertension among men walking $\geqslant 21$ min to work relative to men walking 0–10 min to work 3. Estimated 12% reduction in hypertension risk with 10 min increase in time spent walking to work	Age, BMI, alcohol intake, smoking status, leisure time physical activity, BP, glucose level

Wagner et al., 2001	France & Ireland (*N* = 8865 men 50–59 y.o.)	Self-report time spent walking/cycling to work (energy expenditure)	34.9% regularly walked or cycled to work	1. Higher energy expenditure resulting from walking/cycling to work was related to lower BMI and lower waist circumference and less gain or decrease in BMI over a 5 year period 2. Among subset of men not engaged in vigorous recreational activities, higher energy expenditure from walking/cycling to work was related to lower BMI and lower waist circumference	Leisure time physical activity, high-intensity leisure time activities
Andersen et al., 2000	Copenhagen (*N* = 6914 men & women 20–75 y.o.)	Bicycled or not to work	20.3–27.8% with lower rates among more well educated	1. Lower relative risk of all-cause mortality	BMI, lipids, BP, leisure time physical activity, smoking status, age, sex, education level
Bovens et al., 1993	Netherlands (*N* = 2907 men & women >40 y.o. active in sports)	Bicycled for transport >1 h per week or not	46% of men, 65% of women	1. Among men, transport bicycling was related to lower BMI and higher cardiovascular fitness, but not related to body fat or BP 2. Among women, transport bicycling was related to higher cardiovascular fitness, but not related to BMI or BP; paradoxically, transport bicycling was related to higher percentage body fat	None

Note: BMI = body mass index; LDL = low density lipoprotein cholesterol (“bad” cholesterol); HDL = high density lipoprotein cholesterol (“good cholesterol”); BP = blood pressure; y.o. = years old.

et al., 1990). Although the most common setting for physical activity was the neighborhood street network, proximity of a variety of recreational facilities was related to their use (Giles-Corti and Donovan, 2002). Presence and characteristics of trails have been associated with physical activity (Brownson et al., 2000; Troped et al., 2001). These studies imply that building recreational facilities near homes can promote leisure-time physical activity. It can be hypothesized that placing the facilities within walking or cycling distance of homes could reduce driving to recreational destinations.

Childhood physical activity studies have implications for the transportation field. For example, preschool children were more physically active when there were places nearby where they could play, such as parks (Sallis et al., 1993; Blommaert et al., 1981). Ensuring that playspaces are within walking distance to homes could be expected to both increase children's physical activity and reduce the necessity for parents to drive children to recreational opportunities. There is growing evidence that elementary and middle school children are dependent upon parental transportation to physical activity settings (Sallis et al., 1992b; Hoefer et al., 2001). The need for parents to drive children for physical activity may be a function of suburban land use patterns and a lack of planning for youth mobility, but this remains to be proven.

Health investigators conducting large epidemiological studies have begun to examine the relation between travel behavior and biologic health outcomes. As shown in Table 2, European and Asian studies have documented significant relationships between greater active commuting or transit use frequency and positive health indicators, including lower body mass index, healthier blood lipid profiles, and lower blood pressure associated with active commuting. Many of these associations persisted after controlling for individuals' leisure time physical activity and other factors influencing health (e.g., smoking status). These findings suggest that people's utilitarian active travel have similar health benefits as more traditionally-studied leisure exercise.

Other studies in the health field have evaluated interventions to promote active commuting. The programs are aimed at increasing the percentage of individuals who commute to work by walking or bicycling rather than by motorized transport. Studies have documented increased prevalence and frequency of active commuting to work (Mutrie et al., 2002) and improvements in active commuters' cardio-respiratory fitness (Hendriksen et al., 2000; Vuori et al., 1994). Because cardio-respiratory fitness protects from heart disease and premature death (USDHHS, 1996), these studies show that active community to work has important health benefits. Collaborative studies involving health and transportation professionals are recommended to evaluate the impact of other transportation policies on health-related outcomes.

5. Synergy of transportation and physical activity research: opportunities for collaboration

Although the issue of physical activity and public health seems removed from the daily work of transportation professionals, this review demonstrates that land use, the transportation infrastructure, physical activity, and public health are actually closely interrelated. As the findings reviewed here become more widely known, transportation and land use policies are likely to appear more prominently on the public health agenda. It is unlikely that transportation and land use decisions in the past have been made with consideration of potential effects on physical activity. Now that land use and transportation decisions are shown to affect physical activity, the transportation field needs to put physical activity on its agenda for both practice and research. Transportation professionals need to understand the public health implications of the investments they promote, and hopefully become more involved in multi-sector coalitions seeking to improve public health by increasing physical activity (Sallis et al., 1998).

The present review found the design of communities and transportation systems was consistently related to active transportation, but the effects of environmental and policy variables on total physical activity were not examined. Because large proportions of people in the US live in the low-density and exclusively residential environments associated with low levels of active transport, land use and transportation policies may already be having a substantial but generally undocumented negative impact on public health. Professionals from numerous fields are concerned that we have built communities so it is difficult, and in many cases dangerous, to walk or bicycle and have thus "engineered" physical activity out of our daily lives (Frank, 2000; Frank et al., 2003; Litman, 2003; Sallis et al., 1998; Sallis and Owen, 1999). There is a public health imperative to evaluate environmental and policy variables and their associations with active transport, recreational physical activity, and total physical activity. The results of such studies can inform efforts to alter the environments in which people live their daily lives so as to promote population shifts in physical activity as well as improve transportation systems. Conducting and applying research on environmental correlates of active transport and physical activity will require collaboration among researchers from a wide range of professions (King et al., 2002).

6. Future directions for collaborative research

There are many research topics on which transportation and public health investigators could productively collaborate, and several priority topics are outlined in the Transportation Research Board's (2002) proceedings on environmental research needs. Transdisciplinary collaboration means that professionals from multiple fields work together at deeper levels than combining expertise for specific projects. Transdisciplinary work occurs when the combination of ideas and methods from different fields yields truly new approaches. There are methodologies, conceptual frameworks, and even values within the transportation field that hold particular promise for enriching transportation—health collaborations. A few examples of cross-cutting issues are described here that can enhance the quality of research on many specific topics.

6.1. Expanding conceptual models

As described above, transportation researchers primarily have studied environmental (i.e., land use) correlates of travel behavior, whereas health researchers have primarily examined psychosocial correlates of recreational physical activity. Expanding models of behavior in both fields to include a wide range demographic, psychological, social/cultural, policy, and physical environmental variables has the potential to lead to more powerful explanatory models for transportation and physical activity behaviors (King et al., 2002; Sallis and Owen, 2002). These multi-level "ecological" models not only may improve our ability to explain and predict behavior, they may lead to more effective change strategies to enhance health and quality of life.

6.2. Activity-based travel measures

Research presented here documents how the built environment may influence the choice to walk and bike as forms of transportation and physical activity, but urban form also impacts how we spend our time. The current shift in travel demand modeling from a *trip* to an *activity-based* paradigm allows further investigation into the relationships between urban form and sedentary living. Activity-based data describe allocation of time across trips and *activities*, allowing relations to be examined among travel patterns, urban form, and time use, with physical activity being a component of time use (Frank et al., 2003).

When assessing time used for transportation purposes, a primary consideration is whether there is a perceived travel time budget. This concept implies there is a threshold at which time spent traveling is perceived as no longer reasonable and would account for the common outrage at traffic congestion, when this budget is violated. A travel time budget would imply that time spent in one mode can consume time available for another. Data collected in the Netherlands from 1962 and 1972 showed significant changes in trip rates and time spent traveling per mode for these two points in time. However, the total number of trips and total time spent traveling remained constant across all modes (Hupkes, 1982), and this principle appears to apply to multiple countries (Frank et al., 2003). These findings suggest that increased time spent commuting can lead to reduced time available for walking and biking for both recreation and utilitarian purposes. Transdisciplinary research is required to help us understand how the arrangement of activities, the nature of the linkages between these activities, and the physical design of urban environments influence the duration of time spent engaging in specific types of activities, including active transportation and leisure physical activity.

6.3. Environmental justice and health disparities

Both transportation investments and land use decisions affect public health through a variety of mechanisms. Over the past two decades, the development of environmental justice and clean air policies, each underpinned by public health considerations, have become central issues in urban transportation. Extreme levels of social inequality arising from growing class and race-based disparities in access to jobs and other opportunities have begun to impact transportation policy and, in certain instances, the sub-regional allocation of transportation funds. The term "environmental justice" arose out of evidence that a disproportionate burden of exposure to pollution was being borne by low income and minority populations concentrated in declining central areas of American cities (Schaeffer and Sclar, 1980; Bullard, 1990). This argument was extended to the *burdens* associated with limited transportation options leading to a lack of access to jobs and other *benefits* required for self-advancement among the poor. Recognition of this disparity led to a presidential executive order requiring equitable investment in transportation across income groups (Bullard and Johnson, 1997). Reducing health disparities, particularly between the rich and poor, is one of two central goals of US national health objectives (USDHHS, 2000). Thus, transportation and health share this core value and can assist one another in achieving complementary goals. The transportation field can help achieve physical activity objectives by improving conditions for walking and cycling in low income neighborhoods, and the health field can stimulate and collaborate in research to inform transportation decisions that will reduce population disparities in physical activity.

6.4. The relation of air quality to physical activity

The Clean Air Act Amendments of 1990 (CAAA) required regions to demonstrate the compliance of their transportation investments with the health-based National Ambient Air Quality Standards (NAAQS). Under these requirements, each region's short-term transportation investment program and long-range regional transportation plan are required to conform with the CAAA requirements. In response to emerging evidence on the effects of air pollution on respiratory function, the clean air requirements have changed the definition of an air quality exceedance, or an unhealthy episode, from a 1h high concentration (120 parts of ozone per billion) criterion to a lower (80 parts per billion) concentration over an 8-h period. The proposal to change these standards is the result of recent epidemiological studies linking respiratory function and health with ozone concentration (Friedmann et al., 2001; Koenig, 1999; Pope, 2000; Tolbert et al., 2000). Enforcement is based on the threat of losing federal transportation funds, or at minimum, how these funds are spent. While many regions are not in attainment of the NAAQS at present, most have a plan in place that shows they will have healthy air in the future (Frank, 1998). A conforming plan most often requires enhanced investments in transit, bicycle, and pedestrian facilities to shift travel away from personal vehicles. Because short automobile trips tend to have particularly high emission levels, increased active transport for these short trips could reduce some of the most polluting automobile trips. In some instances, reallocating growth to regional centers is required to reduce trip lengths and to shift travel from auto to transit for models to show lower production of Oxides of Nitrogen, an ozone precursor.

Although transportation is clearly steeped in public health considerations, it is perhaps land use, or the arrangement of activities in the urban environment that has the most direct linkage with public health. Zoning, along with other development regulations, control local land use decisions that have long been legally underpinned by public health, safety, and public welfare (Euclid V Ambler Realty 1926) (Randle, 1989). Current approaches to zoning often result in the segregation of uses, and mandate increased trip distances between destinations (Pendall, 1999). Increased trip distance harms public health in two ways. First, it increases air pollution through increased trip lengths, usually by automobile. Second, as shown consistently in the present review, separated land use reduces walking and cycling for transportation and contributes to low population levels of physical activity.

Increased attention to active transportation could contribute to solutions to a variety of transportation problems, whether the primary motivation is to enhance public health or improve transportation. More walking and cycling for transportation could produce benefits related to traffic congestion, demand for parking, as well as air pollution as previously discussed. The same land use patterns that are associated with active transport are required for the success of public transit, and transit use is consistent with high levels of walking (Frank et al., 2003). Walkable communities are believed to enhance the mobility of children, older adults, and disabled people. However, these expected benefits need to evaluated. Thus, collaborative research between transportation and public health professionals is needed to motivate and guide changes in zoning codes and transportation policies that can solve both transportation and health problems.

7. Conclusion

There are benefits of transdisciplinary collaborative research for both the transportation and public health fields, and opportunities for funding such collaborative research are increasing. The Robert Wood Johnson Foundation is supporting the Active Living Research Program that is funding transdisciplinary research to address many of the questions raised in the present paper (Sallis et al., 2002; www.activelivingresearch.org). The Centers for Disease Control and Prevention (CDC) have been supporting related research through the Active Community Environments (ACEs) program (www.cdc.gov/nccdphp/dnpa/aces.htm). The National Institute for Diabetes and Digestive and Kidney diseases has funded studies to evaluate environmental changes to prevent obesity (www.niddk.nih.gov). The Transportation Research Board (2002) has published a set of research priorities on transportation and health that highlights the links between transportation and physical activity (www.trb.org). Two regions, Atlanta (Frank et al., 2001; www.smartraq.net) and Seattle (LUTAQH; Land Use, Transportation, Air Quality, and Health) are well underway with effective collaborations between transportation and health researchers, practitioners, and decision makers to facilitate the creation of environments that promote physical activity. The Transportation Research Board is partnering with the Institute of Medicine on an analysis of the literature on transportation and health, and this report will identify additional research priorities. These funding opportunities and joint agenda-setting activities are likely to be the initial steps in a long-term relationship between the fields of transportation and public health.

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