An Applied Ecological Framework for Evaluating Infrastructure to Promote Walking and Cycling: The iConnect Study

David Ogilvie, PhD, FFPH, Fiona Bull, PhD, Jane Powell, PhD, Ashley R. Cooper, PhD, Christian Brand, DPhil (Oxon), Nanette Mutrie, PhD, John Preston, PhD, and Harry Rutter, MSc, FFPH, on behalf of the iConnect Consortium

Improving infrastructure for walking and cycling is increasingly recommended as a means to promote physical activity, prevent obesity, and reduce traffic congestion and carbon emissions. However, limited evidence from intervention studies exists to support this approach. Drawing on classic epidemiological methods, psychological and ecological models of behavior change, and the principles of realistic evaluation, we have developed an applied ecological framework by which current theories about the behavioral effects of environmental change may be tested in heterogeneous and complex intervention settings. Our framework guides study design and analysis by specifying the most important data to be collected and relations to be tested to confirm or refute specific hypotheses and thereby refine the underlying theories. (*Am J Public Health.* 2011;101:473–481. doi:10.2105/AJPH.2010.198002)

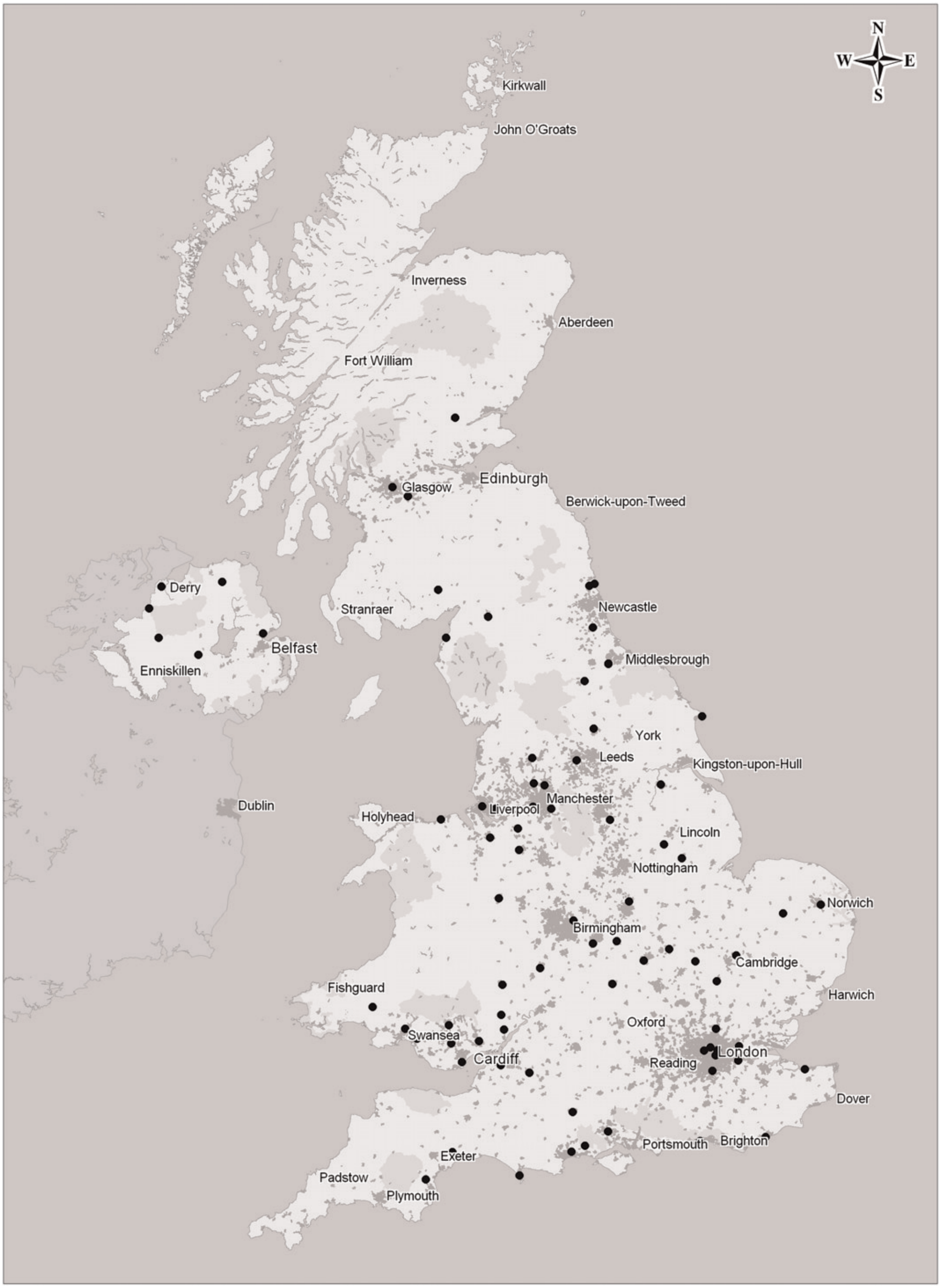
Interest in the relation between transportation and public health traditionally has focused on adverse local effects of motor traffic such as noise, air pollution, and injuries[1] but now also recognizes the potential health benefits of promoting walking and cycling and the wider adverse effects of dependence on motor vehicles.[2] Walking and cycling offer an ideal opportunity for people to incorporate physical activity into their daily lives, reducing their risk of chronic diseases such as diabetes and coronary heart disease.[3,4] A population shift toward more "active travel" also could help reduce traffic congestion and carbon emissions, to which the use of motor vehicles makes a large and inequitably distributed contribution.[5–9]

Improving the infrastructure for walking and cycling recently has been identified as one of the most important policy recommendations for tackling obesity in both the United States and the United Kingdom.[9,10] Such recommendations are largely based on evidence from cross-sectional studies showing that certain characteristics of the physical environment—such as the design of residential neighborhoods and the availability of routes for walking and cycling—may be associated with patterns of physical activity in general and walking and cycling in particular.[11,12] However, evidence is limited from studies of actual interventions to show that altering transportation infrastructure or other aspects of the built environment has led to an increase in walking or cycling or a modal shift away from car use, let alone changes in overall physical activity or carbon emissions.[13–15]

This lack of evidence reflects several unresolved challenges in this area of research, including problems of measurement and evaluation. The difficulty of measuring changes in walking, cycling, and physical activity in general is recognized in both the transportation and the physical activity fields[16–19] and is compounded by the difficulty of applying robust study designs to the evaluation of complex infrastructural interventions.[20] Existing research in this field has an evaluative bias in favor of interventions targeted at individuals, which may be easier to evaluate,[13,14] and is often characterized by methodological limitations such as the lack of representative population samples, prospectively collected data, control groups or areas, or sufficient duration of follow-up.[15] Meanwhile, only limited inferences about the population effects of new infrastructure can be drawn from routinely collected user monitoring data.[21] As a result, we lack the means to assess the potential travel, physical activity, and carbon emission effects of different approaches to promoting walking and cycling, to set appropriate targets, or to allocate resources for new capital projects efficiently.

The Connect2 initiative (available at: http://www.sustransconnect2.org.uk) offers an important opportunity to address both methodological and substantive applied research problems in this multidisciplinary field. Connect2 consists of a program of projects to build or improve local walking and cycling routes at 79 sites around the United Kingdom (Figure 1) led by Sustrans, a charity that promotes sustainable transportation in various ways, including building infrastructure such as the National Cycle Network. Each Connect2 project involves a core landmark engineering project such as a bridge or crossing over a busy road, railway line, or river, which—together with the development or improvement of feeder routes—is intended to make it easier for pedestrians and cyclists to reach destinations in the local area. The iConnect (Impact of COnstructing Non-motorised Networks and Evaluating Changes in Travel) consortium (available at: http://www.iconnect.ac.uk) is an independent multidisciplinary academic collaboration involving 7 United Kingdom universities and the Medical Research Council. The consortium is funded by the Engineering and Physical Sciences Research Council to conduct a 5-year research program to measure and evaluate the effects of Connect2. This collaboration will enable the collection of consistent longitudinal data at multiple sites with which to assess, for the first time, the effects of an infrastructural intervention on outcomes of interest across the 3 domains of travel, physical activity, and carbon emissions.

This first article from the iConnect consortium addresses the challenge of establishing an evaluative framework within which the effects of a complex program of infrastructural investment such as Connect2 can be studied.



Source. Reproduced with permission of Sustrans (Bristol, UK).

FIGURE 1—Map of Connect2 intervention sites: the iConnect study, United Kingdom 2008–2013.

Subsequent articles will address more specific issues of sampling and measurement and the development of a complementary economic evaluation framework.

THE EVALUATIVE PROBLEM

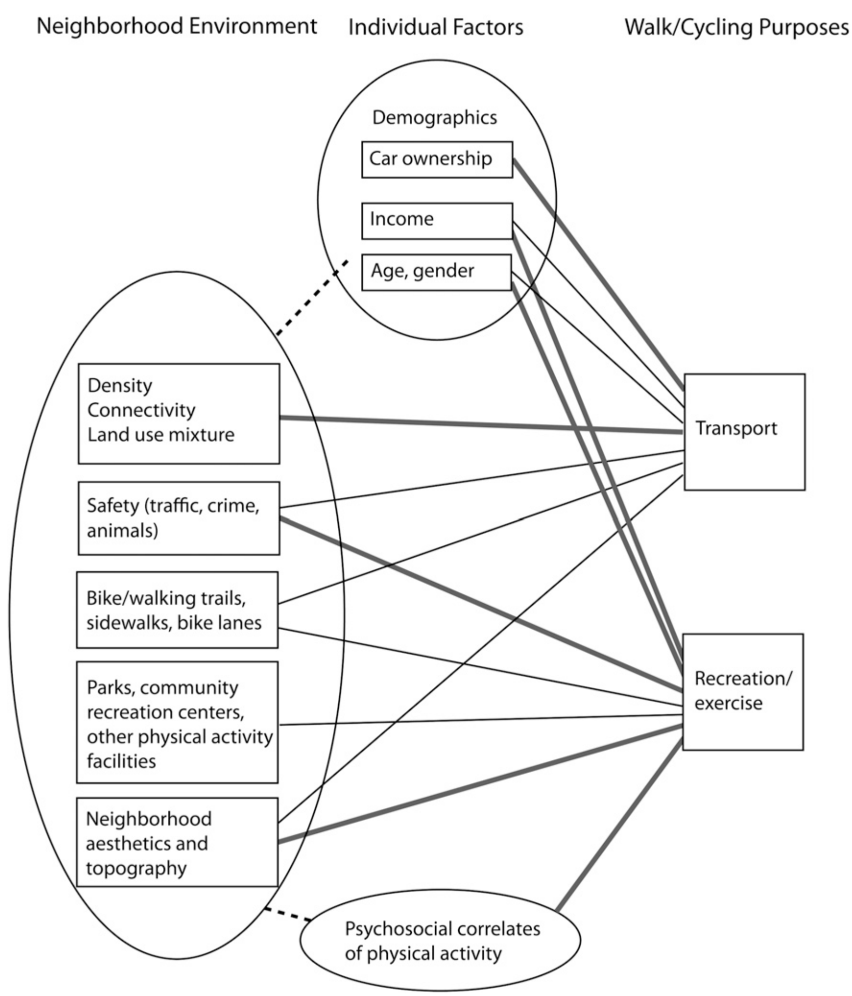
Connect2 is a program of highly diverse infrastructural improvements implemented in a variety of urban, suburban, and rural settings. The intervention at each site will be unique, in terms of both its content (the detail of the engineering project) and its context (the social, community, and topographical environment into which the new infrastructure is inserted). Replication of the overall Connect2 program, or of any single project within it, would therefore not be possible, because the content for a given site would be unlikely to be applicable anywhere else. From an evaluative perspective, Connect2 therefore differs from "soft" (behavioral) interventions to influence travel behavior targeted at individuals (such as Walk in to Work Out),[22] households (such as TravelSmart),[23] or schools (such as Travelling Green)[24] or even some "hard" (infrastructural or engineering) measures such as speed cameras or traffic calming. All of these interventions may be regarded as more-or-less standard packages, albeit implemented with a degree of tailoring to each context.[25] It is possible to replicate these interventions with a relatively high degree of fidelity, to evaluate them on the assumption that one might wish to replicate them, and to cumulate results across different instances of that replication.[26] It is also sometimes possible to evaluate their effects in a randomized controlled trial.[22] None of these conditions applies to a complex infrastructural intervention such as Connect2, so a different approach to evaluation is required to produce consistent evidence in these circumstances.

THE THEORETICAL CONTEXT

It can be difficult sometimes to identify clearly articulated or systematically applied theories underpinning the interventions to promote behavior change studied in published evaluations,[27] particularly those concerned with infrastructural and environmental modification. This difficulty may reflect the fact that many of the currently popular theories or models of behavior change, such as social cognitive theory,[28] the theory of planned behavior,[29] and the transtheoretical model,[30] do not readily encompass the influence of factors in the physical environment. As Owen et al. argued,

> it is too easily assumed, given the focus of social cognitive models on constructs such as attitudes [and] self-efficacy, that conscious individual decision making is the primary determinant of behavioral choice.[31(p75)]

On the contrary, it is increasingly accepted that habitual patterns of behavior may be environmentally cued and that a supportive environment for active living may be a necessary, if not a sufficient, prerequisite for sustained behavior change.[32] We lack a single satisfactory model of how the environment influences behaviors such as walking and cycling,[31] but support is growing for ecological models of behavior capable of encompassing people's transactions with their physical and sociocultural surroundings.[33] Among the models and frameworks developed in this field in recent years,[34,35] the model described by Saelens et al.[11] provides a particularly useful starting point for the iConnect study (Figure 2). It is focused on walking and cycling as the behavioral outcomes of interest, and it shows individual, psychosocial, and environmental factors interacting to influence walking and cycling both as a mode of transportation and as a recreational activity. The model incorporates mediating factors, such as psychosocial factors mediating the relation between recreational cycling and neighborhood characteristics[36]; unlike many other models of this type,[33] it specifies the links between the various constructs (and the strengths of those links) rather than simply listing the constructs of interest.[37] Useful as they are, however, current ecological models of behavior generally specify numerous explanatory variables, or domains of explanatory variables, reflecting their main purpose of explaining multiple influences on people's



Source. Reprinted with kind permission from Springer Science+Business Media: Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*. 2003;25:80–91. Figure 2. Copyright 2003 by the Society of Behavioral Medicine.

FIGURE 2—Saelens' model.

behavior rather than specifying how a particular intervention might lead to a change in behavior.

Our aim was to derive research findings from which some form of generalized causal inference about infrastructural interventions could be made rather than simply to attempt to evaluate the Connect2 program. Even the answer to an apparently simple question as to whether Connect2 had been effective in changing behavior would clearly be highly contingent on what specific types of behavior were studied in what types of people and over what period of time and on the nature of those people's relationships with the particular Connect2 projects chosen for study. Finding a way of reaching more generalizable evaluative conclusions that are both meaningful and scientifically defensible across the relevant research and policy sectors is subject to similar considerations.

Pawson and Tilley[38] argued that evaluative research should test theories about how interventions work cumulatively with context, mechanism, and outcome configurations rather than testing whether a given intervention works in an aggregate, generalizable sense (Table 1). We realized that adopting this realistic approach to evaluation would enable us to acknowledge and exploit the contextual heterogeneity of the different Connect2 projects to design a study capable of illuminating why these interventions are (or are not) effective, in what ways, for whom, and in what circumstances.[38] By moving cumulatively between theory-based abstract configurations and empirical case study–focused configurations, we could produce theory-based empirical results to inform more general conclusions about the merits of investing or disinvesting in different types of interventions or settings rather than claiming to have found a simple recipe for success.[39,40]

THE GENERAL APPROACH

Our general approach therefore was inspired by the opportunity presented by the Connect2 natural experiments[41,42] to develop abstract context, mechanism, and outcome configurations; test focused context, mechanism, and outcome configurations; and refine by realistic cumulation our understanding of the effects of infrastructural interventions of this kind. We do this by combining the perspectives and insights of the most relevant psychological and ecological models of behavior and behavior change with those of the realistic approach to the evaluation of complex interventions. For this purpose, we have defined the Connect2 program as a set of multiple unique implementations of a minimally specified principle, summarized on the Connect2 Web site as "creating new routes for the local journeys we all make every day" (available at http://www.sustransconnect2.org.uk/misc/faqs.php). The constructs of connectivity, permeability—particularly filtered permeability—and accessibility map closely onto this principle (see Box on page 479). In other words, the built environment is redesigned through Connect2 projects to make local journeys easier, more direct, or more pleasant by sustainable modes of transportation than by other (motorized) modes.[43]

THE SPECIFIC SOLUTION

We developed a specific solution to the evaluative problem in 3 stages. The first 2 stages were completed a priori through iterative discussion both within the research consortium and at an expert seminar in Oxford, United Kingdom, in October 2008; the third will be developed through preliminary data collection and analysis. First, we articulated a general theoretical model of the determinants of walking and cycling that forms the background and starting point for the iConnect study. Second, we identified within it a more specific model of the critical putative

TABLE 1—Illustrative Context, Mechanism, and Outcome Configurations: The iConnect Study, United Kingdom

Context	Postulated Mechanism	Postulated Outcome
Example A: Connect2 project to link city center to country park	Now easier and safer to reach park by active modes	Modal shift toward active modes for access to park
	Now easier and safer to reach park by active modes	Increase in overall physical activity associated with visit to park
	Now easier and safer to reach park by active modes	Park users more likely than nonusers to walk or cycle in general after the intervention
	No easier to get anywhere else by active modes	No overall effect on travel to work within city
	Substitution hypothesis: compensatory decrease in activity within park	No change in overall physical activity associated with visit to park
Example B: Connect2 project to link university campus to nearby town	Now easier and safer to reach work by active modes	Modal shift toward active modes for access to work
	No easier to get anywhere else by active modes	No effect on travel for other purposes
	Now easier and safer to reach work by active modes	Net reduction in carbon emissions from private vehicle (car, van, motorcycle) use among employees
	Now easier and safer to reach work by active modes	Net reduction in household car ownership and use (e.g., car given up)
	Now easier and safer to reach work by active modes	Net increase in household expenditure on other activities (potentially carbon intensive) resulting in net increase in household carbon emissions

causal pathways by which we believed the Connect2 projects were likely to work, providing a framework within which the effects of the interventions could be meaningfully evaluated. Third, we will elicit—through interviews with key stakeholders and other informants—the middle-range theory, which explains how particular Connect2 projects are supposed to work in their local context through abstract configurations, and we will combine these insights with our second-stage model to articulate a set of hypotheses expressed in terms of the focused context, mechanism, and outcome configurations described earlier.[38,39] This will be the basis of our claim for making generalized causal inferences from a set of highly contextual and heterogeneous case studies; the evidence derived will help to test and refine a more general theory of active travel (e.g., selectively improving the permeability of the urban environment for cyclists encourages cycling in some contexts but not in others).

Specifying a General Theoretical Model

We first modified Saelens' model[11] by disaggregating psychosocial factors into social, environmental, and household and family factors; relocating some individual psychological factors to the individual group; and placing all these groups of factors within a larger set of macrocontextual factors at each case study site. Second, we highlighted a change in walking and cycling behavior as the main outcome of interest, but those 2 behaviors were treated separately and disaggregated into transportation and recreational purposes to allow for the expectation that these may have different determinants.[17] Third, drawing on the theory of planned behavior, we inserted behavioral intention upstream of the actual observed behavior of interest but recognized that in some circumstances, it may be possible to show only changes in intentions, particularly if those intentions conflict with habit strength for current behavior[44]; we also recognized that a change in intention is not necessarily a prerequisite for a change in behavior. Fourth, we included feedback loops to allow for the possibility that early adopters of travel behavior change at a given site may help pave the way for others by positively influencing the social environment, or others' perceptions of the physical environment, in favor of active travel[45]; also, early experimentation with active travel at the individual level may alter a person's habit strength, moderating his or her response to future travel choices. Finally, we showed that the primary outcome of interest was a subset of 3 larger, directly measurable outcomes (overall travel behavior, overall expenditure on transportation, and overall physical activity), from which other effects of ultimate interest (on net energy use and carbon emissions and on overall health) may be imputed but not necessarily directly measured in this particular study (Figure 3). Although other health effects, such as those related to injuries and air pollution, could be imputed in a study of this kind, the health focus of this particular study was on the potential benefits of any changes in physical activity.

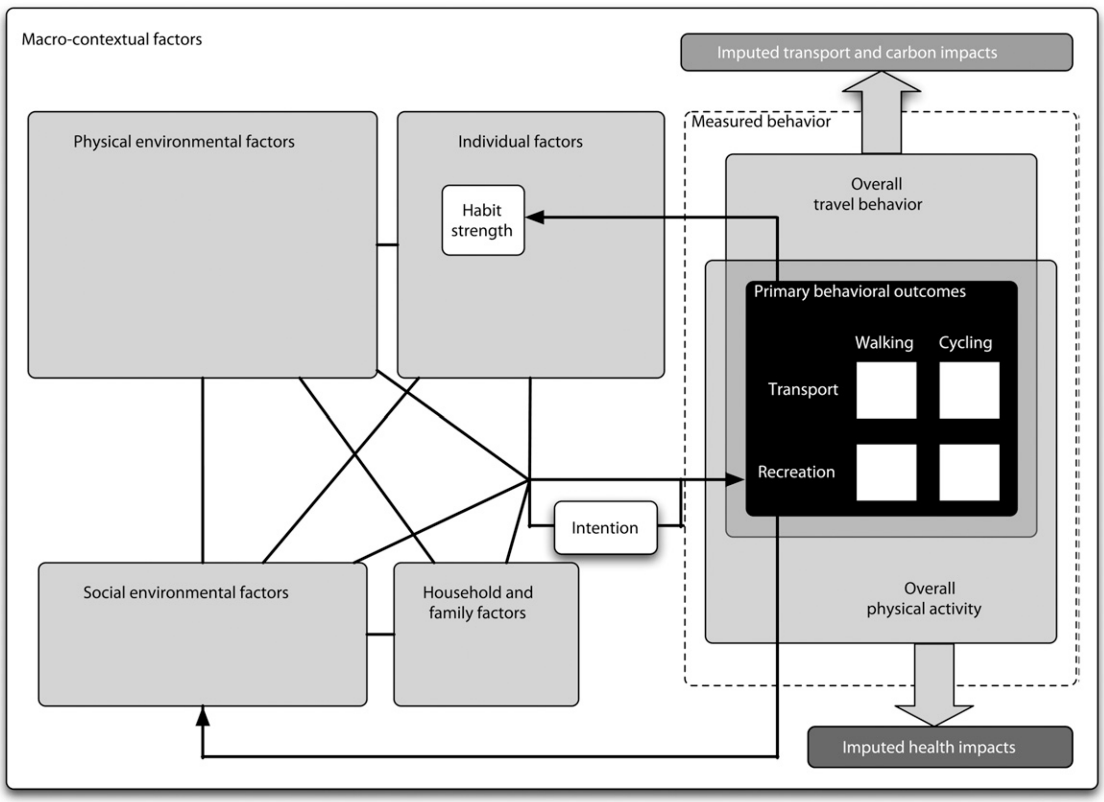


FIGURE 3—General theoretical model: the iConnect study, United Kingdom.

Developing a More Specific Intervention Model

We adopted the following principles. First, as Ball et al.[46] pointed out,

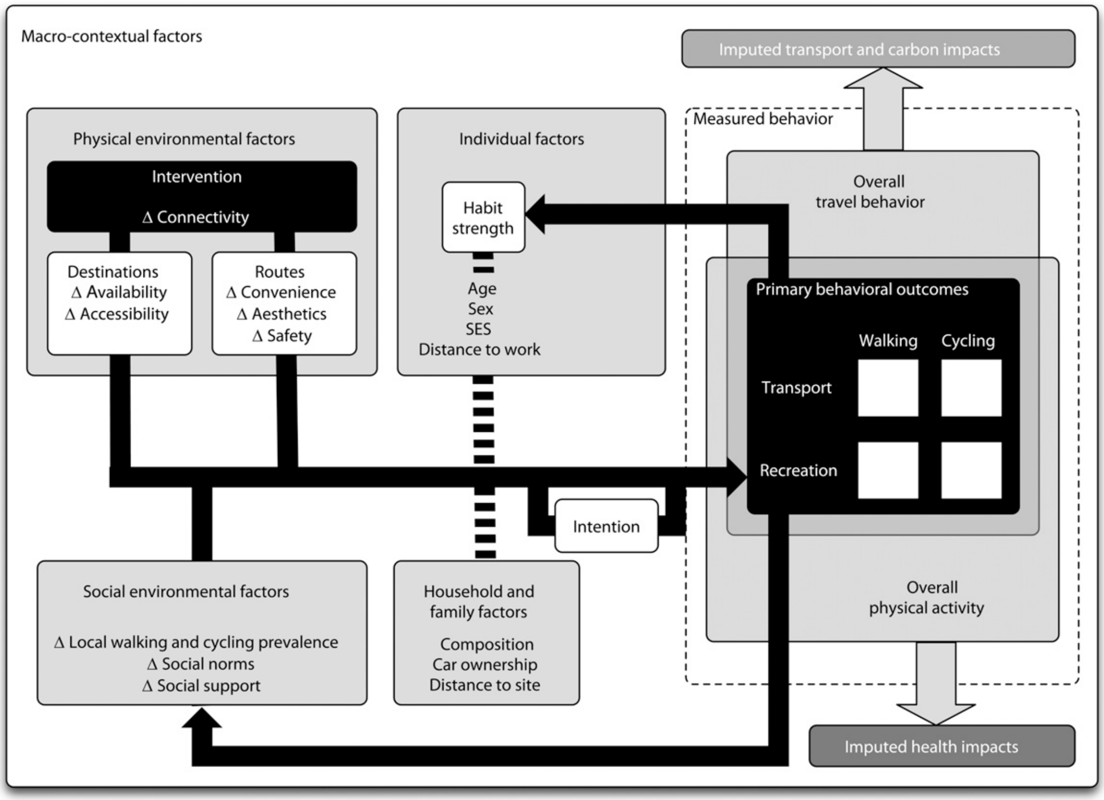
> many studies fail to provide clear justification for the particular exposures selected, and there appears a tendency for studies to be guided more by the data that are available than by careful a priori theoretical selection and conceptualization of key environmental exposures.

Because our objective was to understand the behavioral effects of an intervention, we determined that our model should focus on determinants of behavior that are likely to change as a result of the intervention and to be causally related to changes in behavior. Second, if the intervention can be regarded as a set of multiple unique implementations of the principle of improving connectivity, this construct should lie at the heart of the explanatory model. Third, the model should incorporate the concepts of mediators and moderators (effect modifiers) to allow for greater understanding of behavior change mechanisms and the social distribution of intervention effects.[36,47]

We identified 2 main groups of potential mediating variables: those expected to change as a direct result of the modification of the environment (e.g., altered availability and accessibility of destinations, convenience, safety, and aesthetic quality) and those expected to change as an indirect result of the effects of the intervention on early adopters, whose change in behavior may alter the conduciveness of the local social environment to the uptake of walking and cycling opportunities by others (e.g., perceived social norms, as measured by the strength of agreement with statements such as "I see people in my neighborhood cycling for recreation.").

We also identified 2 main groups of potential moderating (effect-modifying) variables. We expected the response to the intervention to vary not only according to household and family characteristics such as car ownership, household composition, and distance to the intervention site but also according to individual characteristics such as age, gender, and distance to work. Socioeconomic status might be measured at individual, household, or area level, or all 3; in our model, we show this measurement at the individual level solely in the interests of simplicity.

Our simple explanatory model for how the Connect2 interventions are likely to work is shown in Figure 4. The solid connectors indicate the primary putative causal pathway for the intervention, whereas the dotted connectors indicate the primary putative moderators of that causal pathway. We assume that the relative contributions of different factors and pathways within this overall model are likely to vary according to which of the 4 different types of walking and cycling behavior shown as primary behavioral outcomes is being considered.



Note. Solid connectors indicate the primary putative causal pathway for the intervention. Dotted connectors indicate the primary putative moderators of the causal pathway.

FIGURE 4—Specific iConnect intervention model: the iConnect study, United Kingdom.

The application of the model can be illustrated by following an example of a simple set of putative causal relations from left to right across Figure 4. A particular Connect2 project may create a shorter and more direct cycle route from a residential area to a nearby school, altering the accessibility of a key destination. The effect of the increased accessibility may be enhanced if the new route is also perceived to be more convenient, more pleasant, or safer (e.g., if it avoids the need to cross a major highway and includes an off-road section on a traffic-free trail). These changes in the physical environment may lead directly to an increase in students' intention to cycle to school or in the prevalence or frequency of that behavior; such changes may be more likely to occur in some types of students (e.g., boys: individual factors) or households (e.g., those living within a 15-minute cycle ride of the school: household factors) than in others. If the behavior becomes more frequent, a positive feedback loop may be created in which noncycling students (or their parents) begin to perceive the social environment as more conducive to cycling to school because their peers are now more likely to be doing it, leading to a snowball effect as more students take up the opportunity presented by the changes to the physical environment.

Specifying a Set of Specific Hypotheses to Be Tested

We intend to use the evaluative framework described earlier to develop a set of more specific hypotheses (focused context, mechanism, and outcome configurations) that can be tested both within and among a few purposively selected case study sites.

Following the terminology of realistic evaluation,[38] the middle-range theory about how Connect2 projects are supposed to work will be elicited through qualitative interviews with senior Sustrans personnel (for the Connect2 program in general) and with key local stakeholders from Sustrans, local authorities, and other organizations involved with each case study site. We will use the evaluative framework to identify key features of the context of each case study site about which we should collect baseline contextual data. These data may include both population-based data, such as local census data on car ownership, and site-specific contextual factors, such as marketing and other concurrent activities that might be regarded as confounders or contaminating factors in an experimental research design. We will also use the evaluation framework to articulate a set of testable hypotheses based on different context, mechanism, and outcome configurations within and between case study sites and to aid the selection of case study sites that can contribute most to testing these hypotheses. For example, one Connect2 project involves creating a new traffic-free connection between a city center and a nearby country park, whereas another involves creating a new traffic-free connection between a university campus and a nearby town. At such sites, one might propose a set of hypotheses along the lines illustrated in Table 1, focusing (for the purpose of exemplification) on physical activity in the first instance and on carbon emissions in the second.

Many (preferably most) of the chosen hypotheses will be capable of being tested by making use of the diversity both within case study sites (e.g., by comparing the responses of people living closer to and further away from the intervention site) and between case study sites (e.g., by comparing the effects on commuting and leisure journeys at the 2 exemplar sites described earlier). For example, the hypothesis that improving access to work leads to an increase in the use of active modes for commuting could most obviously be tested in the latter case study site (Example B in Table 2), by comparing changes in travel behavior between staff who commute to the campus from the direction served by the new infrastructure and staff who commute from the opposite direction. However, even in a case

Glossary of Terms: The iConnect Study, United Kingdom

Term	Explanation
Transtheoretical model	A model of health behavior change in which individuals progress through 6 stages of change: precontemplation, contemplation, preparation, action, maintenance, and termination.[30]
Realistic evaluation	An approach (originally developed for the evaluation of social programs) that recognizes that the effect of interventions will vary according to the circumstances in which they are applied and therefore asks "why these interventions are (or are not) effective, in what ways, for whom and in what circumstances."[38] It involves developing theories about how particular patterns of outcomes may be produced by particular causal mechanisms being triggered in particular contexts (so-called context, mechanism, and outcome configurations) and testing these theories cumulatively across different instances of the interventions.
Connectivity and permeability	These terms refer to the ease and directness of the movement of people and vehicles in a route network. Although these terms are sometimes used interchangeably, connectivity is sometimes used to refer solely to the number of connections, whereas the concept of permeability also includes the capacity of those connections.
Filtered permeability	A characteristic of a network that is more permeable to certain modes of transportation (in this case, walking and cycling) than others.
Accessibility	This term refers to the proximity of activities, destinations, goods, and services and is a function of population density and land use mix.
Middle-range theory	"Theories that lie between the minor but necessary working hypotheses that evolve in abundance during day-to-day research and the all-inclusive systematic efforts to develop a unified theory."[39] In realistic evaluation, this idea is applied in terms of developing a range of testable specific propositions (families of related context, mechanism, and outcome configurations) based on a small core of more abstract analytical frameworks.[38]

study of a project ostensibly targeted at promoting recreational walking and cycling (Example A in Table 2), a population-based sample of local residents is likely to include some participants for whom the new infrastructure also provides a new route to work; by pooling data on commuters between sites, researchers may be able to examine how the effect of new infrastructure on commuting behavior varies according to socioeconomic position, distance from home to work, lighting of routes, or other characteristics hypothesized to be important, testing intervention theories in a more generalizable way.

An important feature of this approach is the iterative movement between abstract and focused context, mechanism, and outcome configurations across multiple sites to refine understanding. Iteration of this sort means that there is no such thing as the wrong case study site or study population to select for study. It may well be appropriate to predict zero behavior change at certain sites, in certain groups of people, or for certain types of journey, and whatever results are obtained will be used to refine our general theories about how this type of intervention is supposed to work and about the relation between infrastructure and behavior, not to declare the project at any given site a failure.

CONCLUSIONS

We have developed an original theoretical framework for evaluating the public health effect of interventions in the built environment. Our approach represents an innovative and practical response to the methodological issues confronted, achieved by combining the perspectives and insights of classic epidemiology and the most relevant psychological and ecological models of behavior and behavior change with those of the realistic approach to the evaluation of complex interventions. The result may be regarded as an applied ecological model by which current theories about the behavioral effects of environmental change may be tested in heterogeneous and complex intervention settings. Our framework guides study design and analysis by specifying the most important data to be collected (from among the scores of possible variables enumerated in many existing models) and the most important putative causal, mediating, and moderating effects to be tested to confirm or refute specific hypotheses within the overall framework and so refine the underlying theories.

Of course, the key variables and putative causal pathways specified in this framework may turn out not to explain population behavior patterns, and future research may need to include other variables not measured in this study. We will therefore test and refine this model iteratively by applying it as a framework for collecting and analyzing baseline cross-sectional data and, in time, longitudinal data from cohorts of participants at different case study sites. Our approach has wide potential use for other researchers attempting to design and execute evaluations of complex infrastructural interventions in diverse contexts and circumstances. ■

About the Authors

David Ogilvie is with the Medical Research Council Epidemiology Unit and the UKCRC Centre for Diet and Activity Research (CEDAR), Cambridge, UK. Fiona Bull is with the School of Sport, Exercise and Health Science, Loughborough University, UK, and the School of Population Health, University of Western Australia. Jane Powell is with the University of the West of England, Bristol, UK. Ashley R. Cooper is with the Department of Exercise, Nutrition and Health Sciences, University of Bristol, Bristol, UK. Christian Brand is with the Environmental Change Institute, University of Oxford, Oxford, UK. Nanette Mutrie is with the Department of Sport, Culture and the Arts, University of Strathclyde, Glasgow, UK. John Preston is with the School of Civil Engineering and the Environment, University of Southampton, UK. Harry Rutter is with the National Obesity Observatory, Oxford, UK.

Correspondence should be sent to David Ogilvie, PhD, FFPH, UKCRC Centre for Diet and Activity Research (CEDAR), Box 296, Institute of Public Health, Forvie Site, Robinson Way, Cambridge, CB2 0SR, UK (e-mail: david.ogilvie@mrc-epid.cam.ac.uk). Reprints can be ordered at http://www.ajph.org by clicking on the "Reprints/Eprints" link.

This article was accepted July 2, 2010.

Contributors

D. Ogilvie and F. Bull led the development of the evaluation framework, and D. Ogilvie drafted the article. All authors contributed to the conceptual development of the framework and the drafting or revision of the article and approved the final version.

Acknowledgments

The iConnect Consortium is funded by the Engineering and Physical Sciences Research Council (grant EP/G00059X/1). David Ogilvie is also supported by the Centre for Diet and Activity Research, a UK Clinical Research Collaboration (UKCRC) Public Health Research Centre of Excellence. Funding from the British Heart Foundation, Economic and Social Research Council, Medical Research Council, the National Institute for Health Research (NIHR), and the Wellcome Trust, under the auspices of the UK Clinical Research Collaboration, is gratefully acknowledged (available at http://www.esrc.ac.uk/publichealthresearchcentres).

We thank the participants at the first iConnect expert seminar in Oxford in October 2008 for their feedback and contributions to an early version of our evaluation framework and Tim Jones and Yena Song for their additional comments.

This article was written on behalf of the iConnect consortium (available at http://www.iconnect.ac.uk: Christian Brand, Fiona Bull, Ashley R. Cooper, Andy Day, Nanette Mutrie, David Ogilvie, Jane Powell, John Preston, and Harry Rutter).

The Engineering and Physical Sciences Research Council had no involvement in the study design; the collection, analysis, and interpretation of data; the writing of the article; or the decision to submit the article for publication.

Human Participant Protection

No protocol approval was needed for this study.

References

1. McCarthy M. Transport and health. In: Marmot M, Wilkinson R, eds. *Social Determinants of Health.* Oxford, UK: Oxford University Press; 1999:132–154.

2. Maibach E, Steg L, Anable J. Promoting physical activity and reducing climate change: opportunities to replace short car trips with active transportation. *Prev Med.* 2009;49:326–327.

3. Chief Medical Officer. *At Least Five a Week: Evidence on the Impact of Physical Activity and Its Relationship to Health.* London, UK: Department of Health; 2004.

4. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc.* 2007;39:1423–1434.

5. Department for Transport. *Towards a Sustainable Transport System: Supporting Economic Growth in a Low Carbon World.* London, UK: Stationery Office; 2007.

6. Woodcock J, Banister D, Edwards P, Prentice A, Roberts I. Energy and transport. *Lancet.* 2007;370:1078–1088.

7. Potter S. Sustainability, energy conservation and personal transport. In: Warren J, ed. *Managing Transport Energy: Power for a Sustainable Future.* Oxford, UK: Oxford University Press; 2007:93–119.

8. Brand C, Boardman B. Taming of the few: the unequal distribution of greenhouse gas emissions from personal travel in the UK. *Energy Policy.* 2008;36:224–238.

9. Institute of Medicine and National Research Council of the National Academies. *Local Government Actions to Prevent Childhood Obesity.* Washington, DC: National Academies Press; 2009.

10. Foresight. *Tackling Obesities: Future Choices.* London, UK: Government Office for Science; 2007.

11. Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Ann Behav Med.* 2003;25:80–91.

12. Handy S. *Critical Assessment of the Literature on the Relationships Among Transportation, Land Use, and Physical Activity.* Washington, DC: Transportation

Research Board and Institute of Medicine Committee on Physical Activity, Health, Transportation, and Land Use; 2004.

13. Ogilvie D, Egan M, Hamilton V, Petticrew M. Promoting walking and cycling as an alternative to using cars: systematic review. *BMJ*. 2004;329:763–766.

14. Ogilvie D, Foster C, Rothnie H, et al. Interventions to promote walking: systematic review. *BMJ*. 2007;334:1204–1207.

15. National Institute for Health and Clinical Excellence. *Promoting and Creating Built or Natural Environments That Encourage and Support Physical Activity*. London, UK: National Institute for Health and Clinical Excellence; 2008. NICE Public Health Guidance 8.

16. Department for Transport. *Delivery of the National Cycling Strategy: A Review*. London, UK: Stationery Office; 2005.

17. Krizek K, Handy S, Forsyth A. Explaining changes in walking and bicycling behavior: challenges for transportation research. *Environ Plann B Plann Des*. 2009;36:725–740.

18. Stamatakis E, Ekelund U, Wareham N. Temporal trends in physical activity in England: the Health Survey for England 1991 to 2004. *Prev Med*. 2007;45:416–423.

19. Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med*. 2003;37:197–206.

20. Craig P, Dieppe P, Macintyre S, Michie S, Nazareth I, Petticrew M. *Developing and Evaluating Complex Interventions: New Guidance*. London, UK: Medical Research Council; 2008.

21. Cope A, Cairns S, Fox K, et al. The UK National Cycle Network: an assessment of the benefits of a sustainable transport infrastructure. *World Transport Policy Pract*. 2003;9:6–17.

22. Mutrie N, Carney C, Blamey A, Crawford F, Aitchison T, Whitelaw A. "Walk in to Work Out": a randomised controlled trial of a self help intervention to promote active commuting. *J Epidemiol Community Health*. 2002;56:407–412.

23. James B, Brög W. Increasing walking trips through TravelSmart® Individualised Marketing. *World Transport Policy Pract*. 2001;7:61–66.

24. McKee R, Mutrie N, Crawford F, Green B. Promoting walking to school: results of a quasi-experimental trial. *J Epidemiol Community Health*. 2007;61:818–823.

25. Hawe P, Shiell A, Riley T. Complex interventions: how "out of control" can a randomised controlled trial be? *BMJ*. 2004;328:1561–1563.

26. Bunn F, Collier T, Frost C, Ker K, Roberts I, Wentz R. Area-wide traffic calming for preventing traffic related injuries. *Cochrane Database Syst Rev*. 2003;(1):CD003110.

27. Michie S. Designing and implementing behaviour change interventions to improve population health. *J Health Serv Res Policy*. 2008;13(suppl 3):64–69.

28. Bandura A. Health promotion from the perspective of social cognitive theory. *Psychol Health*. 1998;13:623–649.

29. Ajzen I. The theory of planned behavior. *Organ Behav Hum Decis Process*. 1991;50:179–211.

30. Prochaska J, Marcus B. The transtheoretical model: applications to exercise. In: Dishman R, ed. *Advances in Exercise Adherence*. Champaign, Ill: Human Kinetics; 1994:161–180.

31. Owen N, Humpel N, Leslie E, Bauman A, Sallis J. Understanding environmental influences on walking: review and research agenda. *Am J Prev Med*. 2004;27:67–76.

32. Giles-Corti B, Donovan R. The relative influence of individual, social and physical environment determinants of physical activity. *Soc Sci Med*. 2002;54:1793–1812.

33. Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. An ecological approach to creating active living communities. *Annu Rev Public Health*. 2006;27:297–322.

34. Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. *Soc Sci Med*. 2003;56:1693–1703.

35. McMillan T. The relative influence of urban form on a child's travel mode to school. *Transportation Res Part A Policy Pract*. 2007;41:69–79.

36. Bauman AE, Sallis JF, Dzewaltowski DA, Owen N. Toward a better understanding of the influences on physical activity: the role of determinants, correlates, causal variables, mediators, moderators, and confounders. *Am J Prev Med*. 2002;23(2 suppl):5–14.

37. Joffe M, Mindell J. Complex causal process diagrams for analyzing the health impacts of policy interventions. *Am J Public Health*. 2006;96:473–479.

38. Pawson R, Tilley N. *Realistic Evaluation*. London, UK: Sage; 1997.

39. Merton K. *Social Theory and Social Structure*. New York, NY: Free Press; 1968.

40. Greenhalgh T, Humphrey C, Hughes J, Macfarlane F, Butler C, Pawson R. How do you modernize a health service? A realist evaluation of whole-scale transformation in London. *Milbank Q*. 2009;87:391–416.

41. Bauman A. The physical environment and physical activity: moving from ecological associations to intervention evidence. *J Epidemiol Community Health*. 2005;59:535–536.

42. Petticrew M, Cummins S, Ferrell C, et al. Natural experiments: an underused tool for public health? *Public Health*. 2005;119:751–757.

43. Association of Directors of Public Health. *Take Action on Active Travel*. Bristol, UK: Sustrans; 2008.

44. Gardner B. Modelling motivation and habit in stable travel mode contexts. *Transportation Res Part F*. 2009;12:68–76.

45. Killoran A, Doyle N, Waller S, Wohlgemuth C, Crombie H. *Transport Interventions Promoting Safe Cycling and Walking: Evidence Briefing*. London, UK: National Institute for Health and Clinical Excellence; 2006.

46. Ball K, Timperio AF, Crawford DA. Understanding environmental influences on nutrition and physical activity behaviors: where should we look and what should we count? *Int J Behav Nutr Phys Act*. 2006;3:33.

47. De Cocker K, De Bourdeaudhuij I, Brown W, Cardon G. Moderators and mediators of pedometer use and step count increase in the "10,000 Steps Ghent" intervention. *Int J Behav Nutr Phys Act*. 2009;6:3.