

Infrastructure, Programs, and Policies to Increase Bicycling: An International Review

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ABSTRACT

Objectives. To assess existing research on the effects of various interventions on levels of bicycling. Interventions include infrastructure (e.g. bike lanes and parking), integration with public transport, education and marketing programs, bicycle access programs, and legal issues.

Methods. A comprehensive search of peer-reviewed and non-reviewed research identified 139 studies. Study methodologies varied considerably in type and quality, with few meeting rigorous standards. Secondary data were gathered for fourteen case study cities that adopted multiple interventions.

Results. Many studies show positive associations between specific interventions and levels of bicycling. The fourteen case studies show that almost all cities adopting comprehensive packages of interventions experienced large increases in the number of bicycle trips and share of people bicycling.

Conclusions. Most of the evidence examined in this review supports the crucial role of public policy in encouraging bicycling. Substantial increases in bicycling require an integrated package of many different, complementary interventions, including infrastructure provision and pro-bicycle programs, as well as supportive land use planning and restrictions on car use.

Key words: Bicycling; Active Travel; Active Transport; Health; Intervention; Policy; Infrastructure; Sustainable Transportation

Introduction

Bicycling is healthy. That is the conclusion of an increasing number of scientific studies assessing the impacts of bicycling on levels of physical activity, obesity rates, cardiovascular health, and morbidity (Anderson et al., 2000; Bassett et al., 2008; Bauman et al., 2008; BMA, 1992; Cavill et al., 2006; Dora and Phillips, 2000; Gordon-Larsen et al., 2009; Hamer and Chida, 2008; Hillman, 1993; Huy et al., 2008; Matthews et al., 2007; Roberts et al., 1996; and Shephard, 2008). The combined evidence presented in these studies indicates that the health benefits of bicycling far exceed the health risks from traffic injuries, contradicting the widespread misperception that bicycling is a dangerous activity. Moreover, as bicycling levels increase, injury rates fall, making bicycling safer and providing even larger net health benefits (Elvik, 2009; Jacobsen, 2003; Robinson, 2005).

Perhaps due to the increasing evidence of the health benefits of bicycling, many government agencies and public health organizations have explicitly advocated more bicycling as a way to improve individual health as well as reduce air pollution, carbon emissions, congestion, noise, traffic dangers, and other harmful impacts of car use (BMA, 1992; Cavill et al., 2006; Godlee, 1992; OECD, 2004; USDHHS, 1996 and 2008; USDOT, 1994 and 2004; WHO, 2002a and 2002b).

Given the growing consensus on the benefits of bicycling, the important question for researchers is how to increase bicycling. That is the topic of this review paper. Our purpose is three fold: 1) to list, describe, and categorize the wide range of infrastructure, program, and policy interventions to promote bicycling; 2) to summarize the available information on where and to what extent these interventions are currently being implemented; and 3) to assess the actual impacts of the various interventions on levels of bicycling.

There is an extensive and rapidly growing literature that suggests the need to facilitate bicycling through appropriate infrastructure (such as bike paths and bike parking), traffic calming, training and education programs, and other supportive measures. Countries and cities with high levels of bicycling and good safety rates tend to have extensive infrastructure, as well as pro-bicycle policies and programs, while those with low bicycling rates and poor safety records generally have done much less (Pucher and Dijkstra, 2003; Fietsberaad, 2006; Pucher and Buehler, 2008).

Such aggregate comparisons across cities and countries support the general importance of policies for encouraging bicycling and improving safety. However, it is not clear which measures are the most effective and should be given priority in designing and implementing a pro-bicycle policy package. This article assembles the available evidence on the actual impacts of a wide range of policies and programs, first according to specific categories of individual policy measures, and then as packages of coordinated policies and programs.

Methodology

We first developed a list of interventions that are hypothesized to encourage bicycling directly. The list did not include measures such as congestion pricing, gasoline taxation, and car parking policies, which probably influence bicycling levels indirectly. An initial list was reviewed by other experts and practitioners and expanded. While the final list is extensive, it may exclude promising but rare or recently implemented interventions for which studies are not available.

Because few studies measuring the effects of such interventions appear in peer-reviewed journals, we conducted a broad search that also included non-peer reviewed research found in government documents, conference proceedings, and other sources. Using the list of interventions, we conducted electronic searches using Google, Google Scholar, TRIS Online (National Transportation Library), TRANweb, MEDLINE, PUBMED, and ISI Web of Knowledge. We also consulted about 30 Internet websites devoted specifically to pedestrian and bicycling information, and which also post many articles and reports on policy interventions to promote bicycling. The reference lists in each of the located publications were used to identify additional work. We also contacted bicycle researchers and practitioners in the USA, Europe, South America, and Australia to identify potential studies.

The small number of high quality studies prevented us from applying the strict criteria for inclusion used in other related reviews (e.g. Ogilvie, et al., 2004). We decided that including a wider range of studies would help in building the evidence base and assessing research gaps and needs, particularly with respect to methodology.

We only included studies that reported impacts specifically on bicycling as a dependent variable. Studies that combined both walking and bicycling as an outcome measure, e.g. minutes of physical activity, were not included, in contrast to Ogilvie, et al. (2006). Combined measures

were often used in studies evaluating interventions that accommodate both modes, such as paths or trails. Many studies on bicycling interventions focus on safety measures as an outcome, including the number of crashes or interim measures such as distance between bicyclists and motor vehicles. While real or perceived safety levels likely influence levels of bicycling, these studies were not systematically included in this review. Some examples are included when studies with bicycling outcomes are not available.

Studies conducted at both the individual and aggregate (e.g. city or district) levels were included. Both revealed and stated preference studies were included. Revealed preference (RP) studies measure actual behavior, either through self-report (e.g. surveys) or more objective means (e.g. automatic counters or GPS). Stated preference (SP) studies measure people's opinions or intended behaviors. They are often perceived as being less reliable than RP studies. SP methods are often used to test interventions (or packages of interventions) that do not currently exist and, therefore, could not be recorded by RP methods. Sophisticated SP studies provide respondents pairs of choices with different characteristics. For example, a bicyclist might be asked to choose between a shorter route that does not have a bike lane and a longer route that includes a bike path.

We only selected studies that included some quantitative measure of an outcome related to bicycling. Because of the small number of studies and lack of consistency in approaches, we included a wide range of outcomes. Studies that measured the amount of bicycling were of highest priority. At the individual level, this could include, for example, the number of bicycle trips, distance bicycled, or whether or not a person was a bicyclist. At the aggregate level, the share of people bicycling to work was a common measure; the share of all trips by bicycle was reported in some studies. More indirect measures included cyclists' opinions or ratings of interventions.

In some cases, a single evaluation was reported in more than one source, such as a government report, a conference paper, and a peer-reviewed journal article. This review includes only the journal article, unless unique information appears in one of the other sources. Finally, we limited the search to studies in English and focused on studies conducted since 1990. Our search resulted in 139 references that included evidence of the effect of specific interventions on bicycling, of which 65 appeared in peer-reviewed publications (see Tables 1 through 4). That

does not include citations used for the case study cities. Nearly all of the studies were of adults, except for those that focused on school-based interventions.

Results

Travel-related Infrastructure

Perhaps the most common types of intervention are those that aim at separating cyclists from motor vehicles while traveling between origins and destinations. See Table 1 for descriptions of each intervention and results. Striped bike lanes and separate paths are common in North America and Europe, but many European cities also use pavement coloring and other innovations such as cycletracks, which function like a bike lane, but have more physical separation from motor vehicles (see Figure 1 for an example). There were 40 studies that attempted to evaluate the effect or value of bike lanes and/or separated paths. Study methodologies varied widely, including both stated and revealed preference and individual and aggregate-level analysis. Very few of the studies were longitudinal, and there were few quantitative estimates of the effect of facilities on overall rates of bicycling, sometimes because of the methodologies employed. For example, many of the studies used convenience samples of avid cyclists instead of random samples.

Most of the aggregate-level studies found a positive and statistically significant relationship between bike lanes and levels of bicycling, while the individual-level studies had mixed findings. A cross-sectional study at the city-level of over 40 U.S. cities found that each additional mile of bike lanes per square mile was associated with about a one-percentage point higher share of workers regularly commuting by bicycle (Dill and Carr, 2003). A study of Seattle, WA residents found no relationship between the presence of a bike lane (objectively measured) and the odds of bicycling, but did find that being near a path mattered. For example, people living within a half-mile of a path were at least 20% more likely to bicycle at least once a week, compared to people living between one-half and one mile away from a path (Vernez-Moudon et al., 2005).

Stated preference studies almost uniformly found that both cyclists and non-cyclists preferred having bike lanes to riding in mixed traffic. The findings from the studies of off-street paths were varied, with some showing positive associations and others showing no statistically significant relationship. There were only four studies examining two less common (in the USA) **Pucher, Dill, and Handy, “International Review of Cycling Interventions,” *Prev Med* 2010**

types of roadway infrastructure: bicycle boulevards and traffic-protected cycletracks. The findings generally show a positive association between these facilities and bicycling, though without good estimates of the quantitative effects on actual bicycling rates.

Bicycle boulevards employ similar techniques as traffic calmed streets to reduce the number and speed of cars (see Figure 2 for an example). Of the six studies on traffic calming, all but one found positive results, though none rigorously measured the effects on the amount of bicycling. Although car-free zones, home zones, and complete streets also improve the street environment for bicyclists, no studies have measured their effects on the amount of bicycling.

Several studies point to the need to consider characteristics of the bicyclist. At least three studies found differences in facility preferences between men and women, with women generally more attracted to infrastructure with less motor vehicle traffic (Dill and Gliebe 2008; Emond, et al, 2009; Garrard, et al, 2008). However, Emond et al (2009) note that while women liked low-traffic streets, they felt less comfortable than men on off-street paths, perhaps because of security concerns. A majority of the stated preference studies that analyzed both bike lanes and bike paths found that more experienced cyclists preferred the on-street lanes over paths. These cyclists appear less willing to trade-off the additional time required to divert to use separated paths, presumably because they feel more confident in bicycling closer to motor vehicle traffic. These findings are consistent with two recent studies using GPS data and samples of cyclists (Dill and Gliebe, 2008; Harvey, et al., 2008).

Observational studies were more common for analyzing pavement markings aimed at reducing conflicts between motorists and cyclists, including colored lanes, shared lane markings, and bike boxes (also known as advanced stop lines, see Figure 3 for an example). Some, but not all, of the studies concluded that such treatments reduced behaviors that may lead to crashes, such as motorists not yielding to cyclists. None estimated an effect on levels of bicycling. Many researchers hypothesize that if people perceive an increase in safety, they will be more likely to bicycle. Those studies that included surveys of cyclists found an increased perception of safety. Other traffic controls may also affect bicycling. For example, one study shows that a decrease in the number of stops along a route (e.g. due to stop signs or signals) increases bicycling (Rietveld and Daniel, 2004).

End-of-Trip Facilities and Transit Integration

There is a general consensus on the need to provide good bike parking for cyclists—especially secure, sheltered parking to prevent theft and protect bicycles from inclement weather (AASHTO 1999; APBP 2002; Fietsberaad 2006; Litman 2009; Netherlands Ministry of Transport 2009; Pucher 2008; USDOT 2007). Perhaps due to the obvious importance of bike parking, few studies have even attempted to measure the impact of bike parking on bicycling levels. Moreover, it is not clear to what extent the provision of parking facilities follows increased bicycling levels instead of preceding and encouraging more bicycling. The causation is almost certainly in both directions (Fietsberaad 2006; USDOT 2007; Netherlands Ministry of Transport 2009).

Most of the information in Table 2 relates to the nature and extent of the various types of end of trip facilities. In virtually every city we reviewed, the supply of bike parking has been expanding, and many cities have been providing increasing amounts of sheltered parking, guarded parking, and state-of-the-art bike stations which provide a full range of storage, shower, rental, repair, and other services. There are no comprehensive statistics on bike parking supply for any country, and most city statistics only include publicly provided parking spaces.

Some cities monitor the usage of parking facilities, but that is only an indirect reflection of bicycling rates, since bicycles can be parked for hours, days or even weeks. There are few rigorous studies of the impacts of bike parking on bicycling levels. Using multivariate analysis of the UK's National Travel Survey—combined with SP survey data—Wardman et al. (2007) estimated statistically significant impacts of parking and showers on bicycling levels. Compared to a base level of 5.8% of work trips by bicycle, the provision of outdoor bike parking was estimated to raise the bicycle share to 6.3%. Secure indoor parking raised the bicycle share to 6.6%, and to 7.1% when combined with shower facilities. In a stated preference experiment, Hunt and Abraham (2007) surveyed cyclists in Edmonton, Canada and found a statistically significant impact of secure parking at the destination, equivalent to a reduction of 27 minutes of in-route bicycling time. They estimated a much smaller, but statistically significant impact of shower facilities, equivalent to a reduction of 4 minutes of in-route bicycling time.

Bike parking is one of the key aspects of the integration of bicycling with public transport. As noted in Table 3, the focus in Europe and Japan has been on providing massive

amounts of bike parking at rail stations. Bike parking at bus stops is far less common and is mostly in northern Europe, where few if any buses are equipped with bike racks.

Martens (2007) surveyed the impacts of improved bike parking at both rail stations and bus stops in the Netherlands in the context of specific pilot projects during the 1990s to improve integration of bicycling with public transport. He found significant increases in both public transport use and bicycling, but mainly for bicycle trips between home and the suburban rail station (access trip) and far less for bicycle trips between the terminal station and the activity end of the trip (egress trip). Taylor and Mahmassani (1996) estimated a strong preference of cyclists for secure parking at public transport stations, especially in the form of bike lockers.

Martens (2007) notes the success of the Dutch public transport bicycle system (OV-Fiets), which provides convenient and inexpensive short term bicycle rentals (using automated smart card technology) for trips from major train stations to the final destinations of travelers, usually near the city center. The evidence compiled by Martens confirms that better integration of bicycling with public transport leads to more bike and ride trips, and probably to more bicycling overall.

Bicycles on buses and bicycles on rail vehicles are also important forms of integration with public transport, but no studies have explicitly measured their impact on bicycling levels (USDOT 1998; TRB 2005). Some public transport systems in North America (where most of the world's rack-equipped buses are) report usage rates for bike racks on their buses, but time trends are not usually provided, and the results, at any rate, would not necessarily translate into more bicycling.

In short, the few available studies confirm the logical assumption that better bike parking and better integration of bicycling with public transport encourage more bicycling. But the empirical evidence is limited to a few cities, making the results difficult to generalize.

Programs

Programmatic interventions aim to increase bicycling through promotional activities, media campaigns, educational events, and other means (Table 4). Many programs target travel in general, with the goal of reducing vehicle travel by shifting trips to transit, walking, or bicycling. Examples include trip reduction programs, individualized marketing programs, and travel awareness programs, generally focusing on adults. Safe Routes to School programs focus

on children, though infrastructure improvements near schools could also influence adult behavior (Watson and Dannenberg, 2008). Programs that target bicycling specifically include Bike to Work days (or weeks or months) and other promotions, as well as training events.

Evidence on the effect of general travel programs on bicycling is slim. Most evaluations focus on vehicle trip reduction, and impacts on bicycling are often not reported or even measured. The few studies available suggest limited impacts on bicycling, even when programs have a significant effect on vehicle travel; increases in transit use and walking exceed increases in bicycling, in all studies reviewed. Safe Routes to School programs have emphasized walking more than bicycling, and only one study showed a significant increase in the number of students bicycling to school (Staunton, et al., 2003).

The findings for bicycle-specific programs are more encouraging, though few rigorous evaluations of these programs are available. Participation in Bike to Work Days is increasing in many cities, particularly by new bicycle commuters. In San Francisco, bicycle counts remained 25.4% higher one month after the event (LAB, 2008); in Victoria, over one quarter of first time cyclists were still bicycling five months later (Rose and Marfurt, 2007). Other events and promotions have also led to an increase in bicycling. One study shows a lasting effect of a bicycling skills program (Bauman, et al., 2008). Ciclovias are events where streets are temporarily closed to motor traffic, usually on weekends. They have become more common throughout the Americas and attract large numbers of bicyclists (Sarmiento et al., 2010). One study of the ciclovía in Bogota found that riding in ciclovías was associated with more utilitarian cycling as well (Gomez et al, 2005).

Bicycle Access

People cannot bicycle if they do not have access to a bicycle, and studies show that the availability of a bicycle in a household is the strongest single predictor of bicycling for transportation (Cervero et al., 2009). Several different kinds of programs aim to increase access to bicycles, either through facilitating ownership or enabling temporary use of a bicycle (Table 4). Bike sharing programs, sometimes called city bike programs, have grown in popularity throughout the world.

The impacts of these programs are hard to assess, as they are often accompanied by expansion of the bicycle network in anticipation of increased bicycling. Available studies show that these programs are well used and that the share of trips by bicycle has increased in cities that

have implemented bike sharing programs. The share of trips by bicycle increased from 0.75% to 1.76% in Barcelona (Romero, 2008) and from 1.0% to 2.5% in Paris (Nadal, 2007; City of Paris, 2007). In Lyon, bicycle counts increased 75% after implementation of the Velo'v program, with bicycle share reaching 2% in 2007 (Bonnette, 2007; Velo'v, 2009). A study of the OYBike in London showed that 40% of users shifted from motorized modes (Noland and Ishaque, 2006). These results are confounded, however, by improvements in bicycling facilities implemented at the same time as the bike sharing program. Programs in which participants are given bicycles have also led to an increase in bicycling.

Legal Issues

Traffic laws may affect bicycling in different ways (Table 4). Bicycle helmet laws have been controversial. Helmets can help prevent head injuries in falls and crashes, but laws requiring helmet use have been shown to reduce bicycling (Clarke, 2006; Robinson, 2006). Reduced speed limits for motor vehicles increase bicycling in two ways: by increasing the speed of bicycling relative to the speed of driving, and by increasing the safety of bicycling. Most studies, though not all, show an increase in bicycling with lower automobile speed limits.

Case Studies of Comprehensive Packages

It is difficult to isolate the separate impacts of individual policy interventions designed to promote bicycling. For example, the impacts of improved bike parking, bicycling training, and individualized marketing are probably influenced by the extent and quality of the bikeway network. Similarly, bike-to-school and bike-to-work programs are more likely to be successful if residential neighborhoods are traffic calmed. In short, measures to promote bicycling are expected to be interactive and synergistic.

Case studies provide an opportunity to examine the impacts of packages of mutually supportive pro-bicycle policies. Table 5 summarizes case studies of fourteen cities which implemented a wide range of measures to increase bicycling and improve safety. Most of the information comes from detailed case studies of bicycling trends and policies published in Fietsberaad (2006), Pucher and Buehler (2007), Buehler and Handy (2008), and Buehler and Pucher (2009). Some of the information, however, is based on data collected from primary sources for this review (see table for details).

The most important message from Table 5 is that some cities, even very large cities, have dramatically raised bicycling levels while also improving bicycling safety. Berlin, for example, almost quadrupled the number of bicycle trips between 1970 and 2001 and doubled the bicycle share of trips from 5% in 1990 to 10% in 2007. In spite of the sharp rise in bicycling, serious injuries in Berlin fell by 38% from 1992 to 2006. In only six years, the bicycle share of trips within the City of Paris more than doubled from 1% in 2001 to 2.5% in 2007. The bicycle share of trips in Bogota quadrupled from 0.8% in 1995 to 3.2% in 2006. The total number of bicycle trips in London doubled between 2000 and 2008, and bicycle trips to school rose by 75%. Over the same period, bicyclist injuries fell by 12%. Amsterdam raised the bicycle share of trips from 25% in 1970 to 37% in 2005; serious bicyclist injuries fell by 40% between 1985 and 2005. From 1995 to 2003, the bicycle share of trips in Copenhagen rose from 25% to 38% among those 40 years and older. Yet, there was a 60% decline in serious injuries. Between 1990 and 2005-07 (averaged), the number of workers commuting mainly by bicycle in Portland, Oregon more than quadrupled (+329%), while the share of workers commuting by bicycle rose from 1.1% to 3.9%.

Of the medium-sized cities in Table 5, Freiburg, Germany reported the largest increase in bicycling, almost doubling the bicycle share of trips from 15% in 1982 to 27% in 2007. Modest growth was reported for Muenster, Germany (from 29% to 35% of trips), Odense, Denmark (23% to 25%), and Groningen, Netherlands (stable at around 40%). That suggests that it may be difficult to increase bicycling beyond certain already high levels. In both Odense and Groningen, however, the number of serious bicycling injuries fell sharply.

The two smallest cities shown are both in the USA and provide interesting contrasts. In Boulder, Colorado, the share of workers commuting by bicycle rose from 3.8% in 1980 to 6.9% in 2000 and 8.8% in 2006 in response to an aggressive program of bikeway expansion and complementary pro-bicycle measures. By comparison, the share of workers commuting by bicycle in Davis, California fell from 28% in 1980 to 14% in 2000, in spite of extensive bikeways and bike parking. The decline of bicycling to work in Davis is mainly attributable to a sharp increase in long-distance commuting to jobs in other cities in the Sacramento and San Francisco areas.

The fourteen cities showcased in Table 5 are not necessarily representative, but they illustrate a wide range of policy interventions. With so many measures integrated into the pro-bicycle policy package of each city, it would be virtually impossible to disentangle the impacts

of each individual measure. Only in the case of the bike sharing programs in Paris (Velib') and Barcelona (Bicing) can one identify a particular measure that appears to have been most important. Even in Paris and Barcelona, however, several other pro-bicycle interventions were undertaken before and during the bicycle sharing program, including expansion of the bikeway system and bike parking, bicycling education, and traffic calming. Congestion charging in London has been widely credited for increased bicycling there, but it is only one of many programs listed in Table 5 that have encouraged more bicycling since 2000 (Transport for London 2008a, 2008b).

Discussion

This review summarizes the available evidence on the impacts of a wide variety of bicycling interventions around the world. Most of the studies we surveyed suggest positive impacts of such interventions on bicycling levels. As noted by Ogilvie, et al. (2004) in their review of pedestrian and bicycle interventions, "It is difficult to change longstanding and complex patterns of behavior so the evidence that some in-depth, targeted interventions have achieved any measurable shift is encouraging." Moreover, the lack of evidence of a positive effect of some specific interventions is not the same as evidence of a lack of positive effect.

Our review reveals considerable variation in estimated impacts, both by type of intervention and by study design, location, and timing. That makes it difficult to generalize about the effectiveness of individual interventions or of bicycle interventions as a whole. Moreover, measures of bicycling (e.g. number of cyclists, number of bicycle trips, share of trips by bicycle, etc.) are not consistent across studies, making comparisons of estimated impacts difficult. Complicating matters further, some studies do not adequately explain their measures and methods, so it is difficult to assess whether variations across studies are simply an artifact of different methods used rather than a true difference in impacts. Non-peer-reviewed studies conducted by government agencies on their own interventions or by non-governmental organizations that advocate for bicycling policies may raise concerns about potential bias in the reporting of results.

The crucial limitation, however, is that most studies fall far short of the ideal research design for evaluating interventions, involving before and after measurements of a "treatment" and a "control" group (Krizek, et al. 2009). As a result, these studies do not adequately address

the direction of causality, e.g. whether bicycling infrastructure led to increased levels of bicycling, or whether bicycling demand led to investments in bicycle infrastructure. Without an experimental design, it is difficult or impossible to control for other relevant factors such as cost and convenience of car use, income levels, urban form, and other factors that might be more important than explicitly pro-bicycle policies in affecting bicycling levels. In addition, many of the studies we have cited come from the “gray literature” and have not undergone a peer-review process that would provide some assurance of their rigor. Due to these many limitations, the empirical results summarized in this review should be viewed with caution.

Several factors probably moderate the effects of bicycling interventions. For example, land use planning in northern Europe is regionally coordinated and generally restricts low-density, car-oriented sprawl (Schmidt and Buehler, 2007). By promoting compact, mixed-use development, European land use policies generate shorter trip distances more readily covered by bicycle. Restrictions on car use also affect bicycling. The much higher cost of car ownership and use in northern Europe encourages bicycling, especially combined with limited car parking, car-free zones, comprehensive traffic calming, and lower overall speed limits, which reduce the overall convenience and attractiveness of car use (Pucher and Buehler, 2008). The lack of such car-restrictive policies in the USA probably reduces the impacts of policy interventions to increase bicycling.

The current level of bicycling in a community also affects bicycling safety and the potential to further increase bicycling. Several studies have demonstrated the principle of “safety in numbers.” Using both time-series and cross-sectional data, they find that bicycling safety is greater in countries and cities with higher levels of bicycling, and that bicycling injury rates fall as levels of bicycling increase. As the number of cyclists grows, they become more visible to motorists, which is a crucial factor in bicycling safety. In addition, a higher percentage of motorists are likely to be bicyclists themselves, and thus more sensitive to the needs and rights of bicyclists. The presence of large numbers of bicyclists may also help underpin their legal use of roadways and intersection crossings and generate public and political support for more investment in bicycling infrastructure (Elvik, 2009; Jacobsen, 2003; Robinson, 2005).

Culture, custom, and habit tend to foster bicycling in cities with high bicycle shares of trips but deter bicycling—especially among non-cyclists—in cities with low levels of bicycling where it is viewed as a fringe mode (Pucher et al., 1999; de Bruijn et al., 2009). Non-cyclists in

bicycle-oriented cities may respond differently to policy interventions than in cities with few cyclists. Thus, the very same infrastructure provision, program, or policy might have different impacts on bicycling in different contexts, making it risky to generalize about the effectiveness of any individual measure.

In addition, there are important limitations to the evidence provided in the studies we surveyed that may mask the full effects of any particular intervention. The small estimated impacts of some of the specific infrastructure improvements examined in this review should not be misinterpreted as justification for not undertaking incremental steps toward a full system. Infrastructure measures are almost always implemented in stages, and not all at once. Many studies we examined only measured the impacts of incremental expansions and did not capture the full impact of a completed system. That might account for the small estimated impacts of some specific infrastructure improvements. A complete system of bicycling infrastructure (e.g. lanes, paths, cycletracks, bike boxes, traffic signals, parking, etc.) may have far more impact than the sum of its individual parts. Similarly, some specific programs might appear to have negligible impact when examined in isolation but significant impact when implemented comprehensively. Even more important, a coordinated package of complementary infrastructure measures, programs, and policies may enhance the impact of any intervention that is a component of that package.

Indeed, the most compelling evidence we found came from communities that have implemented a fully integrated package of strategies to increase bicycling. The cases reviewed here suggest that a comprehensive approach produces a much greater impact on bicycling than individual measures that are not coordinated. The impact of any particular measure is enhanced by the synergies with complementary measures in the same package. In that sense, the whole package is more than the sum of its parts. However, the more successfully a city implements a wide range of policies and programs simultaneously and fully integrates them with each other, the more difficult it becomes to disentangle the separate impacts of each measure. Both the apparent success of the comprehensive approach and the complexity of dissecting its effects point to a need for a meta-level approach to evaluation that examines the impacts of different sets of strategies across a large number of cases, taking into consideration the potential moderating factors in each of the cases examined, rather than a focus on the impacts of specific interventions in isolation.

It is also important to note the small number of studies, whether peer-reviewed or from the gray literature, for many of the interventions we examined. The vast majority of interventions do not include an evaluation component that would provide evidence of the impact of the intervention on the amount of bicycling. Public agencies and other organizations implementing interventions should collect before and after data on bicycling in order to facilitate the analysis of effectiveness. The development of standardized instruments to measure bicycling (e.g. household survey instruments, or protocols for bicycling counts) would facilitate data collection for resource-strapped agencies and organizations. Ideally, they would work with academic researchers in designing and carrying out the evaluation, including data collection and analysis, and would publish the results through the peer-review process. Research funding targeted at evaluating interventions through such partnerships would help to build a reliable and valid evidence base.

Despite all these caveats and the pressing need for additional research, a clear message emerges from our review: Some individual interventions can increase bicycling to varying degrees, but the increases are not usually large. That does not mean that individual interventions are not important, but they are most effective as a part of a more comprehensive effort. Substantial increases in bicycling require an integrated package of many different, complementary interventions, including infrastructure provision and pro-bicycle programs, as well as supportive land use planning and restrictions on car use.

There are many role models for cities to follow, as suggested by Table 5. Indeed, Bogota became a bicycling success story by importing Dutch bicycle planners and adopting many of the pro-bicycle measures found in the Netherlands. But it added its own particularly South American program of Ciclovias. Cities with successful bicycling policies can be found in many countries, providing experience about the most appropriate package of policies for local conditions.

Virtually all the available evidence indicates that policies make an important difference: not only explicitly pro-bicycle policies but also transport policies in general, housing and land use policies, and car pricing and restraint policies. Designing the appropriate mix of policies for each city's particular situation requires careful planning and ongoing citizen input, especially from bicyclists. Emphasizing the proven health benefits of bicycling will be key to garnering the public and political support necessary to implement a truly comprehensive package of policies.

That multi-faceted, coordinated approach offers the promise of substantial growth in bicycling, even in cities with low bicycling levels.

Conflict of Interest Statement

All authors declare that they have no conflict of interest.

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Precis

Most studies of individual interventions found positive, though variable, effects on bicycling. Case studies show that large increases in bicycling result when interventions are implemented as a coordinated package of mutually reinforcing measures.

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Table 1: Travel-Related Infrastructure for Bicycling

Measure	Description	Examples and extent of implementation	Measured effects on amount of bicycling
Overall measures of “bikeability”	Some studies combine several infrastructure features into single indices or ask respondents to rate the overall environment for bicycling	Not applicable	One Austrian study found that people who agreed that there were bicycle “tracks” along their route and possible shortcuts were about twice as likely to bicycle as those who did not (Titze, et al., 2008). One revealed preference (RP) survey of cyclists found a positive association between their overall rating of the quality of bicycle facilities and frequency of bicycle commuting (Sener, et al., 2009). One study did not find a significant relationship between ratings for the bikeability on streets around elementary schools and the number of bicycles parked at the schools (Sisson, et al., 2006).
On-road bicycle lanes	In the USA., bicycle lanes are usually designated with a white stripe, a bicycle icon on the pavement, and signage. The lanes are on each side of the road, to the right of motor vehicle lanes, and are recommended to be at least five feet wide (American Association of State Highway and Transportation Officials (AASHTO), 1999).	Lanes are very common in U.S. cities, though to varying degrees. Data for 43 of the 50 largest cities in the USA found from zero to 1.5 linear miles of bike lanes per square mile of area (Dill and Carr, 2003).	<p>Cross-sectional studies at the city- or district-level show positive correlation between bike lanes or paths and levels of bicycle commuting (Dill and Carr, 2003; LeClerc, 2002; Nelson and Allen, 1997; Parkin, et al., 2008; Pucher and Buehler, 2005). Two longitudinal studies found that new bike lanes and paths were associated with increases in bicycle commuting, though effects were sometimes mediated (Barnes, et al., 2006; Cleaveland and Douma, 2009).</p> <p>Four of five RP studies conducted at the individual-level did not show a positive correlation (Cervero, et al., 2009; de Geus, et al., 2008; Dill and Voros, 2007; Vernez-Moudon, et al., 2005). Krizek and Johnson (2006) found that people living within 400 meters of a bike lane were more likely to bicycle. Two of the studies found positive association between the <i>perception</i> of having bike lanes and paths and bicycling (Dill and Voros, 2007; Vernez-Moudon, et al., 2005). Some RP studies of route choices show that cyclists go out of their way to use bike lanes or paths (Dill, 2009; Dill and Gliebe, 2008; Howard and Burns, 2001; Krizek, et al., 2007).</p> <p>Several stated preference (SP) studies show a preference for bike lanes over no facilities or that bike lanes would encourage more bicycling (Abraham, et al., 2002; Akar and Clifton, 2009; Antonakos, 1994; Bureau of Transportation Statistics, 2004; Emond, et al., 2009; Hunt and Abraham, 2007; Krizek, 2006; Landis, et al., 1998. Madera, 2009; Parkin, et al., 2007; Stinson and Bhat, 2003; Tilahun, et al., 2007; Wardman, et al., 2007). Experienced cyclists may prefer bike lanes to off-road paths (Akar and Clifton, 2009; Antonakos, 1994; Bureau of Transportation Statistics, 2004; Hunt and Abraham, 2007; Stinson and Bhat, 2003; Tilahun, et al., 2007) or have little or no preference for striped lanes over no striping (Taylor and Mahmassani, 1996; Sener, et al., in press).</p> <p>Before and after counts in several North American cities and London (UK) show increases in number of cyclists after bike lanes installed (City of San Francisco, 2004; City of Toronto, 2001; City of Vancouver, 1999; Federal Highway Administration, 1994; Sallaberry, 2000; San Francisco Department of Parking and Traffic, 2001; Transport for London, 2004a). However, only one city included counts on nearby streets, where it was found that cyclists were likely diverted to the bike lane (City of San Francisco, 2004).</p> <p>Four studies looked at the effect of bike lane markings on behavior related to safety, but did not include measures of changes in the amount of bicycling. (Hunter, et al., 1999, Harkey and Stewart, 1998; Daff and Barton, 2005; Van Houton and Seiderman, 2005).</p>

Two-way travel on one-way streets	Contra-flow bike lanes allow bicyclists to travel in the opposite direction on one-way streets. False one-way streets use signage or barriers to allow cyclists to enter a street, but not motor vehicles. Two-way motor vehicle travel is allowed, but less common because of the entry restriction.	Contra-flow lanes and similar treatments are common in many European cities, usually on urban residential streets with low traffic speeds. They are rare in the USA (Nabti and Ridgway, 2002), where current guidance discourages the practice (AASHTO, 1999).	No studies were found that assessed changes in levels of bicycling. A study of six sites in the UK concluded that the treatments were safe when designed correctly. A large majority of surveyed cyclists felt safer with the treatments (Ryley and Davies, 1998). A German study found no negative effect on traffic safety (Alrutz et al, 2002). A before-after study of three locations in London found no significant change in the number of crashes. At a fourth location where bicycling flow rates were available a significant decrease in the crash rate was found (Transport for London 2005).
Shared bus/bike lanes	Bus-only lanes, usually in downtown environments, that allow bicycle travel.	Shared bus/bike lanes have been used in many European and Australian, and some North American cities, including Toronto, Ontario, Santa Cruz, CA, Philadelphia, PA, and Washington, DC. (Nabti and Ridgway, 2002)	Surveys in the UK found that shared bus/bike lanes were popular with cyclists. For about one-quarter of the cyclists, the lane influenced their route choice, and few delays to buses were observed (Reid and Guthrie, 2004).
Off-street paths	Off-street paths are paved and separated from motor vehicle traffic. They usually accommodate two-direction bicycle traffic. The minimum recommended width is 10 feet (American Association of State Highway and Transportation Officials (AASHTO), 1999). The term “trail” is sometimes used for this type of facility. However, transportation planners use the term trails to refer to unimproved (e.g. unpaved) recreational facilities (AASHTO, 1999). Paths can be mixed use (including pedestrians, rollerbladers, etc.) or limited to cyclists.	Off-street paths are common in U.S. cities, though the number of miles is often limited. A survey of 50 large cities found a range of less than 0.1 to over 3.0 linear miles of paths per square mile of area (Thunderhead Alliance, 2007). Most paths in the USA are for mixed travel, though some have lane markings to separate cyclists from pedestrians and other users.	One RP study showed a positive correlation between likelihood of bicycling and proximity to separate paths (Vernez-Moudon, et al., 2005), while another found no effect (Krizek and Johnson, 2006). RP studies have found conflicting evidence as to whether cyclists go out of their way to use paths (Aultman-Hall, et al., 1998; Dill, 2009). One SP survey found that about 40% of cyclists intercepted preferred a longer route using a path to a shorter route using a motor vehicle lane (Shafizadeh and Niemeier, 1997). One observational study found that women cyclists preferred separate paths over bike lanes, and both facilities over no facilities (Garrard, et al., 2008). One intercept survey of bicyclists on paths found that 20% stated they would change modes if off-road facilities were not available (Rose, 2007). Several SP studies found that less confident cyclists prefer separate paths over lanes (see above; Jackson and Ruehr, 1998). Respondents in one survey were more comfortable on a path compared to a four-lane local street with a bike lane, though there was no difference between the path and a two-lane local street with a bike lane (Emond, et al., 2009). Five sources looked at paths before and after construction or the introduction of bicycles. Two did not show a change in levels of bicycling for nearby residents (Burbidge and Goulas, 2009; Evenson, et al., 2005). One showed an increase in minutes of bicycling among residents living within 1.5 km, when combined with a marketing campaign (Merom, et al., 2003). Two studies showed an increase in the number of cyclists (Cohen, et al., 2008; Transport for London, 2004a).
Signed bicycle routes	“A shared roadway which has been designated by signing as a preferred route for bicycle use.” (AASHTO, 1999) For this review, these routes do not include striped lanes or other pavement markings.	Signed bicycle routes are very common in U.S. cities. They may be more common on residential streets or other streets with less motor vehicle traffic.	One RP survey found a positive correlation between cyclists’ perception of facility quality and the presence of signed shared roadways, though not as strong as with bike lanes. Facility quality was then positively associated with the frequency of commuting by bicycle (Sener, et al., 2009). One SP study found that cyclists preferred residential roads designated as a bicycle route slightly more than residential roads without such designation (Abraham, et al., 2002).
Bicycle boulevards	Bicycle boulevards are signed bicycle routes, usually on low-traffic streets, that also include other traffic calming features that discourage motor vehicle traffic, such as diverters and traffic circles.	Bicycle boulevards are much less common in the USA than bike lanes or paths. Portland, OR, Berkeley, CA, and Palo Alto CA have implemented bicycle boulevards (Nabti and Ridgway, 2002).	One RP study found that cyclists went out of their way to use bicycle boulevards. Women and less-experienced cyclists demonstrated a particular attraction to the facilities, more so than to bike lanes on major streets (Dill and Gliebe, 2008). One survey found that respondents were most comfortable bicycling on a “quiet street” (Emond, et al., 2009).

Cycletracks (sometimes referred to as sidepaths or raised bike lane)	Cycletracks are similar to bike lanes, but are physically more separated from motor vehicles, for example with a curb, vehicle parking, or other barriers. They are often wider than a typical U.S. bike lane and usually do not allow pedestrian travel.	Cycletracks are common in European cities on major streets with higher volumes of motor vehicle traffic, but very rare in the USA (Nabti and Ridgway, 2002)	One before-after study of new cycletracks in Copenhagen reported a 20% increase in bicycle and moped traffic and a 10% decrease in motor vehicle traffic. However, it was not known how much of the change was due to changes in route choice versus people shifting from driving or other modes to bicycling (Jensen, 2008a). An evaluation of a two-way cycletrack in London showed a decrease in the <i>rate</i> of bicycling crashes (Transport for London, 2005) and a 58% increase in the number of cyclists on the roadway in 3.5 years (Transport for London, 2004a). Surveys of Danish adults and German cyclists both found that respondents rated cycletracks higher than striped bike lanes (Bohle, 2000; Jensen, 2007).
Colored lanes	Paint or other methods are used to color bike lanes, making them more visible to motorists.	Colored on-street bike lanes are common in European cities, but rare in the USA. Some U.S. cities have used color to mark short segments of lanes at potential conflict points, such as intersections or on-ramps.	Two studies looked at raised and colored cycletracks through intersections in Sweden. One found that the volume of cyclists increased compared to two non-treatment intersections, and estimated that the safety risk declined (Garder, et al., 1998). Several studies looked at various safety measures as outcomes, but not levels of bicycling (Konig, 2006, Jensen, 2008b, Hunter, et al., 2000, Sadek, et al., 2007, Hunter, 1998).
Shared lane markings	Shared lane markings, also known as sharrows, are used in lanes shared by motor vehicles and bicycles to alert drivers to the potential presence of cyclists and to direct cyclists on where to ride.	Shared lane markings are rare in the USA, though use is expected to increase	No studies were found that measured levels of bicycling. Two studies measured safety outcomes, such as distances between cyclists and parked cars and cyclists and passing motorists (Alta Planning + Design, 2004, Pein et al, 1999)
Bike boxes (also known as advanced stop lines)	Bike boxes are marked areas at a signalized intersection, in front of the motor vehicle lane, where cyclists can wait while the light is red. The boxes are intended to make cyclists more visible to motor vehicles and give them a head start through the intersection (depending upon the design)	Bike boxes and advanced stop lines are used in many European cities. They have also been installed in Melbourne, Australia, Christchurch, New Zealand, and three cities in Canada (Toronto, Vancouver, Victoria). The concept is relatively new in the USA, though at least eight U.S. cities have installed bike boxes, including several in Portland, OR..	Studies show a wide range of results in terms of appropriate usage by cyclists and encroachment by motor vehicles (Allen, et al., 2005; Atkins, 2005; Daff and Barton, 2005; Hunter, 2000; Newman, 2002; Rodgers, 2005; Wall, et al., 2003). Four studies did not find a reduction in conflicts, because there were either no or too few conflicts observed (Allen, et al., 2005; Atkins, 2005; Hunter, 2000; Wall, et al., 2003). A London study concluded that ASLs did not have a significant positive or negative effect on cyclist safety (Transport for London, 2005). Surveys of cyclists in three studies indicate that a majority felt safer with the bike box (Newman, 2002; Rodgers, 2005; Wall, et al., 2003). One study found that a majority of cyclists did not understand the purpose of the bike box (Hunter, 2000).
Bicycle Phases – Traffic Signals	Separate traffic signal phases for bicycles at intersections can provide time for cyclists to cross an intersection without motor vehicle traffic	Bicycle phases for signals are common in European cities, particularly with cycletracks, but rare in the USA. They have been used in Davis, CA, New York, NY, and Portland, OR (Nabti, and Ridgway, 2002).	One study in Davis, CA estimated that the benefits (mainly reduced crashes) greatly outweighed the costs and disbenefits (including changes in vehicle capacity) of a separate bicycle phase at an intersection with a high volume of bicycle traffic connecting to an off-street path. In the 35 months before installation there were 10 auto-bicycle collisions at or near the intersection, compared to none in the 35 months afterwards (Korve and Niemeier, 2002).
Maintenance of facilities	Pavement quality and the presence of debris on paths and in lanes could influence bicycling decisions and safety	No data is available assessing the quality of bicycle facilities nationally.	One study found that pavement quality was negatively correlated with the share of residents in an area bicycling to work (Parkin, et al., 2008). The number of cyclists on a path in London doubled after the path was resurfaced (Transport for London, 2004a). A U.S. study found that pavement quality was a significant predictor of cyclists' rating of a road segment (Landis, et al., 1998). In one survey, cyclists rated "smooth pavement" as high as having a direct route and higher than having a bike path, though lower than having a bike lane (Antonakos, 1994)
Wayfinding signage	Wayfinding signs for cyclists usually include common destinations and the distance or time to bicycle there	Wayfinding signs are being used by more U.S. cities.	There were no studies that measured the effects of wayfinding signage on levels of bicycling.

Techniques to shorten cyclists' routes	Cut-throughs provide cyclists but not motor vehicles with a more direct connection. Right-turn shortcuts allow cyclists to turn before reaching an intersection.	Cut-throughs are sometimes used as a traffic calming technique in the USA. We could not identify any examples of right-turn shortcuts specifically for cyclists, not associated with separate from a path, in the USA.	There were no studies that measured the effects of cut-throughs or right-turn shortcuts.
Other traffic controls			A Netherlands study found that 0.3 fewer stops per km along a route meant a 4.9% higher share of bicycling (Rietveld and Daniel, 2004).
Traffic Calming	A combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized users" (Lockwood, 1997). Physical measures include vertical deflection (e.g. speed humps) or horizontal deflection (e.g. bulb-outs, neck-downs, or chicanes). Traffic calming techniques are used on bicycle boulevards, though programs tend to focus on pedestrians more than cyclists.	Traffic calming has its roots in neighborhood-based efforts in the Netherlands in the 1960s to tame traffic on residential streets (Clarke and Dornfeld, 1994). Officially endorsed by the Dutch government in 1976, the concept spread throughout Europe and to Japan, Australia, and North America over the next decade. In 1999, the Institute of Transportation Engineers published a report on the state of traffic calming practice in the USA (ITE, 1999). Traffic calming programs for local streets are common throughout the USA, though the scale and sophistication of the programs varies considerably.	Although a 1994 study concludes that "the experience from Europe clearly shows that bicycle use has been encouraged by traffic calming" (Clarke and Dornfeld, 1994), few rigorous studies are available to support this claim. The impact of traffic calming on vehicle speeds is well documented, but evidence on the degree to which reduced speeds lead to reductions in accidents or increases in bicycling is slim. Studies in Germany in the early 1980s showed a doubling of bicycling in the small town of Buxehude (Doldissen and Draeger, 1990) and a 50% increase in bicycle use in the Berlin-Moabit area (Commission of the European Communities, 1989). A study in Japan in the 1980s found that bicycle traffic volumes rose along most routes, though the magnitude of the increase was not reported (Clarke and Dornfeld, 1994). A Danish study noted a 20% increase in bicyclists crossing a major road after traffic calming in one of three towns (Herrstedt, 1992). In the 1990s, a traffic calming project in the city of Cambridge, MA led to an increase in perceived safety: 33% of residents reported that cyclist safety was better, while only 8% said it was worse (Watkins, 2000). In the Berlin-Moabit area, bicyclist accidents declined by 16% (Commission of the European Communities). Bicycle accidents rose in Buxtehude, but these were primarily non-injury accidents (Doldissen and Draeger, 1990).
Home Zones	Home zones are a form of traffic calming that focuses on residential streets. Streets are designed or altered to serve as play areas as well as streets, and speed limits of 10 mph are enforced. Physical elements may include benches, flowerbeds, trees, lamp posts, play structures, and pavement treatments.	The home zone concept derives from the "woonerf" – or "living yard" – movement in the Netherlands in the 1960s. Home zones are common in the Netherlands, Germany, the U.K., and other parts of Europe. The U.K. Department for Transport promotes the home zone concept. The concept has not been adopted in the USA, though examples of streets that follow the principles of home zones can be found.	An evaluation of nine home zone schemes in the U.K. found no change in adult bicycle ownership. Among adults with bikes, 80% said the home zone made no difference in how often they bicycled within the zone, 10% said they bicycled more often, 10% said they bicycled less often. Among cyclists, 60% said bicycling in home zones was not different, 30% said more pleasant, 10% said less pleasant. Among children with bicycles, 57% used it with the same frequency, 22% used it more often, 21% used it less often; 28% thought bicycling more fun now, 10% less fun, and 62% about the same (Webster, et al., 2006).

Car-Free Zones	Car-free zones generally take one of three different forms: (1) Temporary closure of roads to motor vehicle traffic. In South America, these programs are called “ciclovias” (see Table 4). (2) Pedestrian malls, usually in central business districts, where several blocks have been closed to vehicle traffic, with limited exceptions. (3) Car-free neighborhoods, in which residents must park motor vehicles at a remote parking facility.	Although common in European cities, pedestrian malls are limited in the USA. Well-known examples include Pearl Street in Boulder, CO, Third Street Promenade in Santa Monica, CA, Ithaca Commons, in Ithaca, NY, and Faneuil Hall/Quincy Market in Boston, MA. Many cities in the USA experimented with pedestrian malls in the 1960s and 1970s but later removed them when businesses in the mall failed to thrive. Car-free neighborhoods are much less common than pedestrian malls. One of the most famous examples is Vaubon in Freiberg, Germany. In North America, examples are mostly limited to resort-oriented islands, such as Mackinac Island in Michigan.	Several case studies provide evidence of a shift in mode split for people entering the central business district after conversion to a pedestrian mall, though the impact on bicycling appears limited. In Bologna, Italy, vehicle traffic declined by 50%, and 8% of those arrive at the center came by bicycle after the conversion (Topp and Pharoah, 1994). In Lubeck, Germany, of those who used to drive, 12% switched to transit, walking, bicycling; bicycling was not separately reported (Topp and Pharoah, 1994). In Aachen, Germany, car travel declined from 44% to 36%, but bicycling stayed constant at 3% (Topp and Pharoah, 1994).
Complete Streets	The complete streets concept asserts that streets are not just for vehicles but for all potential users, including pedestrians, cyclists, transit users, wheelchair users, shopkeepers, residents. Complete streets policies, taking many different forms, establish the complete streets concept as the guiding design principle for new and rebuilt streets.	Complete streets policies had been adopted by 25 local and regional governments in the USA and by 10 states as of 2007 (Thunderhead Alliance, 2007). The U.S. Congress is considering a federal complete streets policy. The number of projects built according to complete streets principles is growing.	No evidence on the impact of complete streets policies or projects on bicycling levels is publicly available at this time.

Table 2 Bike Parking and End-of-Trip Facilities

Measure	Description	Examples and extent of implementation	Measured effects on bicycling
Bike parking	General	<p>Quantity and quality of bike parking rising sharply in many European, North American, and Australian cities, and in some Asian and South American cities. No comprehensive national data available, but selected city data show doubling or tripling of bike parking supply in many cities over past two decades (Pucher and Buehler 2006, 2007, 2008 and 2009; Fietsberaad 2006; Litman 2009; Thunderhead Alliance 2008)</p> <p>Incomplete statistics generally include public bike parking but not privately provided parking at residences, workplaces, and commercial buildings, or at schools and universities</p> <p>Increasingly, cities are requiring provision of specific levels of bike parking in newly constructed buildings and offer incentives via green building guidelines such as LEED (USA), BREEAM (UK); CASBEE (Japan) and Green Star (Australia) (Litman 2009; Kessler 2008; U.S. Green Building Council 2005; Pucher 2008)</p>	<p>Hunt and Abraham (2007) estimated large and statistically significant impacts on bicycling of secure parking at the destination, equivalent to a reduction of 27 minutes in bicycling time in route.</p> <p>Noland and Kunreuther (1995) estimated that availability of safe bike parking at work significantly raised perception of bicycling convenience and raised likelihood of bicycling to work.</p>
	Unsheltered/Sheltered	Most parking is in unsheltered bike racks on sidewalks, plazas or open parking lots. There is a trend toward sheltered parking, at least covered with roof of some sort.	Multivariate analysis of UK National Travel Survey by Wardman et al. (2007) found significant impacts on bicycling to work. Compared to base bicycle mode share of 5.8% for work trips, outdoor parking would raise share to 6.3%, indoor secure parking to 6.6%, and indoor parking plus showers to 7.1%. Suggests that such end of trip facilities have important impact on decision to bicycle to work.
	Guarded	Trend in northern Europe (esp. Netherlands, Germany, Denmark) toward guarded parking to prevent theft, both in special facilities such as bike stations as well as outdoor parking that is guarded by attendants	
	Bike lockers	Usually at train or metro stations, especially in North America, where it is the main form of sheltered, secure bike parking	Taylor and Mahmassani (1996) estimate significant impacts of secure bike lockers for cyclists at public transport stations
Showers at workplaces	Usually combination of showers, clothes storage, and change facilities; often in conjunction with bike parking facilities	Infrequent but increasing provision due to building codes in some cities that require such facilities and encouraged by green building codes such as LEED and BREEAM, which award credit points for such facilities	Wardman et al. (2007) estimated significant impact of shower facilities on bicycling to work; Abraham and Hunt (2007) estimate small but statistically significant impacts of shower facilities at the destination, equivalent to a reduction of 4 minutes in in-route bicycling time.
Bicycle stations	Full-service facilities offering secured, sheltered bike parking in addition to bicycle rentals, bicycle repairs, showers, accessories, bicycle washes, bicycle touring advice, etc. (Pucher and Buehler 2007, 2008, and 2009; Pucher 2008; Litman 2009; Martens 2007). Stations are usually adjacent to train or metro stations as a key form of integration with public transport, but sometimes in commercial districts of city centers	In 2007, bike stations at 67 Dutch train stations and 70 German train stations, with capacity of up to 10,000 bikes; only 10 bike stations, mostly small (100-300 bikes) in North America in 2009; large bike stations in Tokyo and a few other Japanese cities (Martens 2007; Harden 2008)	No studies have measured impacts of bike stations on bicycling, but presumably positive, since such bike stations are generally well utilized due to security, convenience and wide range of services offered

Table 3 Integration of Bicycles with Public Transport

Measure	Examples and extent of implementation	Measured effects on bicycling
Parking at rail stations	Most important form of integration with PT in Europe and Japan, with large amounts of bike parking at most suburban rail and many metro stations, often in form of bike stations (Pucher and Buehler 2008; Fietsberaad 2006; Dutch National Railways 2009); massive bike parking at Japanese rail stations, with 740,000 bikes parked at Tokyo's metro and train stations every day (Harden 2008); over 350,000 bike racks at Dutch train stations (Martens 2007; Dutch National Railways, 2009)	Rietveld (2000), Martens (2004 and 2007), Brunsing (1997), Hegger (2007), McClintock and Morris (2008), Pucher and Buehler (2009), and Netherlands Ministry of Transport (2009) find that provision of good bike parking at public transport stations increases PT use as well as levels of bicycling. TRB (2005) estimates that all forms of bike and ride are much cheaper than park and ride for access to PT stops.
Parking at bus stops	Less common and mostly restricted to northern Europe, due to lack of bike racks on buses	No studies available.
Bike racks on buses	Most common in North America, with 72% of US buses equipped with bus racks, and 80% of Canadian buses; rare in Europe (APTA 2008; TRB 2005; Pucher and Buehler 2009; Thunderhead Alliance 2008)	Most studies focus on impacts of bike racks on bus use, and find positive impacts, generating more revenues than costs of installing racks (Hagelin 2005). Surveys of PT systems find high and increasing use of bike racks (USDOT 1998; TRB 2005).
Bikes on rail cars	Usually permitted during off peak hours on most suburban rail, metro, and light rail systems in both Europe and North America; often special space on rail cars reserved for bikes, sometimes with bike racks or hooks; many systems prohibit bikes during peak hours (Pucher and Buehler 2009; TRB 2005)	Evidence suggests high level of use but insufficient capacity to handle bikes during peak hours; no formal studies of impacts on bicycling levels, but probably positive, since it helps cyclists cover long portions of trip by public transport while using their bikes to reach PT stops and access destinations (USDOT 1998; TRB 2005; Pucher and Buehler 2009)
Short-term rental bikes	Most widely implemented in Europe, using Smart Card technology, with OV-Fiets public transport bicycle rentals at 156 Dutch rail stations and Call-a-Bike rentals at 16 German train stations (Martens 2007; Pucher and Buehler 2008), but expanding with new bicycle rental systems such as Velib' in Paris, Velo'V. in Lyon, and Bicing in Barcelona, with many rental stations near metro and train stations (Litman 2009; Martens 2007; Holtzman 2008; DeMaio and Gifford 2004)	Martens (2007) and Litman (2009) report increased bicycling as well as increased PT usage as a result of such rental programs

Table 4 Programs and Legal Interventions to Promote Bicycling

Measure	Description	Examples and extent of implementation	Measured effects on amount of bicycling
General Travel Programs			
Trip Reduction Programs	Employer-based programs that aim to reduce vehicle travel, usually by shifting commute mode to transit, walking, and/or bicycling. Programs, often mandated by law, may include promotions, financial incentives, and provision of facilities. Called “Travel Plans” in the U.K.	Trip reduction programs are common in the USA in metropolitan areas with high levels of congestion and /or air quality problems.	Evaluations usually focus on reductions in vehicle travel rather than increases in bicycling. Examples in the U.K. show increases in bicycling: Manchester Airport tripled bicycle trips to work, with parking charges and improved bicycle access and facilities, between 1996 and 2000; in Stockley Park, bicycling more than doubled, in late 1990s (Rye, 2002). A parking cash-out program in the USA led to a 39% increase in walking and bicycling combined (Shoup, 1997). In a study of the “Mobility Management” policy in the Netherlands, 8 employers reported increases in bicycling (1% to 8%), one no change, and one a decrease (-3%) (Touwen, 1997). A “Walk in to work out” educational campaign that included substantial information on bicycling had no impact on bicycling at 3 Glasgow workplaces (Mutrie, et al., 2002). One stated preference study concluded that financial incentives of £2 per day would not increase bicycle commuting (Ryley, 2006)
Individualized Marketing, aka TravelSmart and SmartTrips	These are comprehensive marketing programs aimed at individuals in a neighborhood, school, or worksite. The programs usually involve targeted information, events, and incentives, such as transit passes or coupons to bicycle stores.	Programs were first implemented in Europe by Socialdata and targeted public transport (Brog, 1998). TravelSmart programs have been implemented throughout Australia and in a handful of U.S. cities, though the number is increasing. More recent programs in U.S. cities are branded under different names, such as SmartTrips in Portland, OR.	A review of before & after evaluations found an increase in bicycle trips in 10 of 11 Australian neighborhood programs as well as increases in bicycling to 8 of 10 worksite programs (Australian Greenhouse Office, 2005). Evaluations of programs in Portland and other US cities found increases in the share of all daily trips made on bicycle (Brog and Barta, 2007; Cooper, 2007; Portland Office of Transportation, 2007; Socialdata America, 2005; City of Portland Office of Transportation, 2006; City of Portland Office of Transportation, 2005). In eight neighborhood programs in Australia and the USA., the increase ranged from one to two percentage points (e.g. from 3% to 4% of all trips); in the other cases it was less than one-half of one percentage point. Many of the programs show larger increases in walking and transit use, also targets of the marketing.
Travel Awareness Programs	A wide variety of programs designed to reduce driving and increase use of transit, walking, and bicycling, usually implemented by local governments or community organizations.	The number and variety of programs that fall into this category appear to be growing, although no inventory is available. The “In Town Without My Car!” program, which dates back to the mid-1990s, reportedly affected over 111 million inhabitants in 1035 participating cities and 428 supporting cities in 2003 (Cairns, et al., 2004). Programs are more common in Europe than in the USA.	Evaluations of media campaigns tend to focus on marketing-style outcomes – e.g. how many people noticed campaigns, what they remember from it – rather than change in travel behavior. Awareness of travel behavior campaigns range from 17% to 76%; 20-40% is common (Cairns, et al., 2004). The You-Move-NRW campaign in North Rhine-Westphalia, Germany in 2002, involving a contest for school children to propose projects to reduce driving, led to an increase in transit use but a decline in bicycling among participants (Reutter, 2004).
Safe Routes to School	Safe Routes to School (SR2S or SRTS) programs include education, encouragement, infrastructure, and enforcement programs aimed at increasing the safety and number of students walking and bicycling to school.	The movement is believed to have started in Denmark in the 1970s. Programs in the USA increased in number starting in the 1990s (Boarnet, et al., 2005). SRTS is now funded at the federal level, with programs in every state (Davison, et al., 2008). Nearly 4,500 schools were reported to be participating in state-funded programs at the end of 2008 (National Center for Safe Routes to School, 2008)	Only a handful of studies so far measure the effects of a SRTS program on bicycling. A study in Marin County, CA, one of the earliest programs in the USA, found a 114% increase in the number of students bicycling to school (Staunton, et al., 2003). An examination of infrastructure projects at ten California schools found some increasing in walking, but no observed effect on bicycling (Boarnet, et al., 2005). However, only one of the schools included bicycle-specific improvements. Only four of the 125 SRTS projects reviewed in a California study have measurements of bicycling and walking activity. In only one case did the number of students bicycling to and from school change noticeably, from 23 before the project to 39 after (Orenstein, et al., 2007).

Bicycling Specific Programs			
Bike to Work Days	Bike to Work Days (BWDs) are promotional events that encourage commuters to try bicycling. Events may take place over a day, week, or month, and may include free breakfasts, give-aways, contests, and other activities.	Bike-to-Work events are popular in metropolitan areas in the USA. The number of programs and the numbers of participants in individual programs have grown.	There is some evidence that BWDs increase bicycling beyond the event. The number of “first time riders” has increased in many programs: in Seattle, from 845 new commuters in 2004 to 2474 in 2008; in Portland, from 433 in 2002 to 2869 in 2008 (LAB, 2008). In San Francisco in 2008, bicycle counts at a central point were 100% higher on BWD and 25.4% higher several weeks later; bicycle share was 48.3% before BWD, 64.1% on BWD, and 51.8% afterwards (LAB, 2008). In Victoria, Australia, 27% of first time riders on BWD were still bicycling to work 5 months later (Rose and Marfurt, 2007).
Ciclovias (or ciclovias-recreativa”)	Free mass recreational programs where streets are temporarily closed to motorized traffic and reserved for use by pedestrians, runners, roller bladders, and cyclists.	These events started in the 1960s in San Francisco, Seattle, and Sao Paolo, and gradually spread throughout the Americas (Sarmiento, et al., 2010). Since 2000, there has been rapid growth: 25 new programs have started, for a total of 38 cities with on-going programs in the Americas. South America currently has the largest and most frequent ciclovias. Many other cities in the Americas, Europe, and Australia occasionally close off streets for non-motorized events, often as part of car-free days.	The most comprehensive study of these events reports minutes of physical activity generated by the ciclovias without distinguishing between bicycling and other means of movement (Sarmiento, et al., 2010). Using cross-section data, Cervero et al. (2009) found that proximity to ciclovía bikeways is associated with higher levels of ciclovía use. Also using cross-section data, Gomez et al. (2005) found an association between recreational riding on ciclovias and utilitarian cycling such as bike trips to work. Bogota has the world’s largest ciclovía with 123km of streets closed to cars and 700,000 to 1 million participants. Bogota’s bicycle mode share has tripled as the popularity of the ciclovía has grown, but the scale of this ciclovía makes it an exceptional case (Parra et al., 2007; IDRD, 2004; IDU, 2009; Montezuma, 2005; Despascio, 2008).
Other Bicycle Promotions	Examples of other types of bicycle promotions include bicycle film festivals (Horton and Salkeld, 2006), bicycle “buses” (Bauman, et al 2008), recreational bicycle events (Bauman, et al. 2008), and bicycle awareness campaigns (Greig, 2001).	Promotional programs are common in Europe, Australia, and increasingly in the USA. No inventory of all such programs is available.	Recreational bicycling events have led to increased levels of bicycling for participants (Bowles, et al., 2006; Godbold, 2005). The Cycle Instead campaign in Perth, Australia, involved two 30-second commercials, shown over a period of 4 weeks, plus supporting activities (e.g. community events) and media (e.g. newspaper ads, give-away items); bicycling among surveyed respondents increased from 29% to 36% (Greig, 2001). A program in Davis, CA to promote bicycling to youth soccer games appears to have led to an increase in bicycling (Tal and Handy 2008).
Education/Training	A variety of programs are designed to increase bicycling skills and knowledge of bicycling laws.	In the USA, the League of American Bicyclists certifies trainers for six different courses; 200 instructors were certified in 2005. Other education/training programs are offered by local governments and community organizations. No inventory of all such programs is available.	There are few rigorous evaluations of bicycling skills programs and their impact on bicycling, but evidence shows an increase in skills and confidence. An evaluation of a program run by Central Sydney Area Health Service showed that 56% of participants were bicycling more two months after the program (Telfer, et al., 2006).
Bicycle Access Programs			

Bicycle Sharing Programs	These programs offer short-term rentals for a nominal fee and sometimes require a one-time or annual membership fee. Bicycles can be picked-up and returned at designated spots around the city, usually through an automated system.	Bicycle sharing programs have evolved through three generations since the 1960s, starting with a free bicycle program established in Amsterdam in 1964. Recent programs employ advanced technology to provide access to bikes and to track them. Bicycle sharing programs are already operating in 89 European cities and are now spreading to cities elsewhere in the world, including the USA (DeMaio 2009a and 2009b).	Evaluations focus on use of the program rather than impact on bicycling overall. Rentals per bicycle per day average 5-12 in Paris, 6.4 in Lyon, 6 in Barcelona (Ecoplan, 2009; DeMaio 2009a; Holtzman 2008; Buehrmann 2008). Estimated trips generated per day by bicycle sharing range from 19,100 in Lyon, to 30,000 in Barcelona, to 70,000-145,000 in Paris. (Ecoplan, 2009; DeMaio, 2009a; Bonnette, 2007). Evidence on increases in bicycle mode share after implementation of bicycle sharing programs is confounded by improvements in bicycling facilities at the same time. Bicycle share reportedly increased from 0.75% in 2005 to 1.76% in 2007 in Barcelona (Romero, 2008), from 1.0% in 2001 to 2.5% in 2007 in Paris (Nadal, 2007; City of Paris, 2007); from 0.5% in 1995 to 2% in 2006 in Lyon, with a 75% increase in bicycle counts from 2005 to 2007 (Bonnette, 2007; Velo'V., 2009). In London, 68% of OYBike trips were for leisure or recreation; 6% of users reported shifting from driving and 34% from transit, while 23% said they would not have travelled (Noland and Ishaque, 2006).
Other Access Programs	Programs to increase bicycle access include give-away programs, loaner programs, fleet programs, and service and repair programs.	No inventory of such programs is available.	In the BikeBus'ers pilot project in Arhus, Denmark in 1995-96, participants were given a new bicycle and bus-tickets free for a year, as well as other services, in exchange for signing a contract promising to reduce driving; bicycling for "everyday trips" increased from 8% to 40%, while bicycling to work increased from about 15% to about 60% (Bunde, 1997; Overgaard-Madsen, undated). In the Cycle 100 program in Australia, 100 participants given a mountain bicycle and equipment replaced 12,000 km of commuting by car with bicycling (Bauman, et al. 2008).
Legal Interventions			
Helmet Laws	Helmet laws require cyclists of all ages or of specified ages (e.g. under 18 years old) to wear helmets.	In the USA, helmet laws were first adopted by state and local governments in 1985. There are 22 state and at least 192 local helmet laws; only 14 states have no state or local laws (BHSL, 2009). In Australia, helmets are mandatory in all states and territories. Helmets are generally not required in European countries.	Mandatory helmet laws have been shown to increase helmet use but also to reduce bicycling. Studies in Australia in the 1990s found declines in bicycle counts one year after the implementation of a helmet law of 36% in Melbourne, 36% in New South Wales, and 20% in Perth (Clarke, 2006; Robinson, 2006).
Speed limits	Reduced speed limits for vehicle traffic to improve safety for cyclists and pedestrians and to improve environmental quality (e.g. noise).	Reduced speed limits are often put in place as a part of traffic calming programs (see Table 1). The Department for Transport in the U.K. has promoted 20mph zones.	Reduced speed limits for vehicles potentially increase bicycling in two ways: by increasing the speed of bicycling relative to the speed of driving, and by increasing the safety of bicycling. In Graz, Austria a general 30 km/hr speed limit reduced bicyclist accidents by 4% (Sammer, 1997). Wide spread automobile speed limits in Hilden, Germany led to a significant increase in bicycling (Bauman, et al., 2008). Studies in the U.K. show an increase in willingness of residents to bicycle but no evidence of an actual increase in bicycling in 20 mph zones (Babtie Group, 2001).

Table 5 Case Studies of Cities Implementing Multiple Interventions

City (population)	Trends in bicycling levels and safety	Bicycling infrastructure and programs	References
London, UK (7,557,000)	Doubling in total number of bicycle trips from 2000 to 2008 (+99%); average annual growth of 17% between 2003 and 2006, after implementation of congestion charging; 75% increase in bicycle trips to school 2000-2008. Bicycle share of all trips (all trip purposes) rose from 1.2% in 2003 to 1.6% in 2006, an increase of 43; 12% reduction in serious bicycling injuries from 2000 to 2008	<ul style="list-style-type: none"> • Development of London Bicycling Network since 2000, mainly through bike routes on lightly traveled streets, but also selective installation of bike lanes, bus-bike lanes, contra-flow bike lanes, and mixed-use ped/bike paths: 4,000km total length of which 550km are special facilities of some sort, but not usually traffic-separated • Traffic calming of some residential neighborhoods through roadway design modifications and 20mph speed limit; installation of many pass-throughs (short-cuts) for cyclists and pedestrians to provide more convenient, faster connections • 640 intersections were modified via advance stop lines (bike boxes) for cyclists; some intersections offer bike turning lanes and special marking of lanes where crossing intersection, cyclist-activated traffic signals at some intersections • Installation of over 65,000 bike parking spaces since 2000, of which 15,000 have been at London schools, and over 5,000 additional spaces at public transport stops • Widespread introduction of bicycling training since 2000, now in all 33 boroughs, at over 600 schools in London in 2008 • Over 100 Transport for London (TfL) and London Bicycling Campaign (LCC) community bicycling projects to promote bicycling among specific target groups • Over 3 million copies of TfL/LCC bike route maps distributed free of charge • Congestion charging in Central London, begun Feb 2003, imposing £5 per day fee for private cars, workdays 7:00-18:30 workdays, raised to £8 in Feb 2005; expansion of charging zone in Feb 2007, 7:00-18:00. 	Transport for London (2004b, 2008a, 2008b)
Bogota, COL (7,881,000)	0.8% of trips in 1995 to 3.2% in 2003; participation in Ciclovía grew from 5,000 in 1974 to over 400,000 in 2005	<ul style="list-style-type: none"> • From 1998 to 2000, 344km of separate bike paths built, connecting to public transport and major destinations • Ciclovía: closure of 121 km of roadways to cars on Sundays and holidays, used mainly for bicycling • Car-free day, first Thursday of February, starting in 2000 • Restrictions on motor vehicles on certain days of the week depending on license plate numbers ("pico Y. plata") • Creation of extensive car-free zones and streets; removal of cars from many public spaces; restrictions on car parking • Extensive educational campaign to raise environmental awareness and improve motorist behavior vis a vis cyclists and pedestrians 	Parra et al. (2007); IDRD (2004); IDU (2009); Montezuma (2005); Despacio (2008); Cervero et al. (2009)
Berlin, GER (3,400,000)	Total number of bicycle trips almost quadrupled from 1975-2001 (275% increase); bicycle share increased from 5% of trips in 1990 to 10% in 2007; 38% decline in serious injuries 1992-2006	<ul style="list-style-type: none"> • Network of separate bicycling facilities tripled from 271km in 1970 to 920km in 2008; also 70km of bus-bike lanes and 100km of shared-use paths • 3,800km of residential streets (72% of all roads) are traffic calmed at 30km/hr or less, including many home zones with 7km/hr limit • Internet bicycle trip planning site tailors routes to range of preferences • 22,600 bike parking spots at regional rail and metro stations • Mandatory bicycling education for all schoolchildren • Call-a-bike program of German railways has over 3,000 bikes available for short-term rental at train stations, unlocked for use via mobile phones • Wide range of special bicycle rides, promotional events 	City of Berlin (2003); Pucher and Buehler (2007)

Paris, FR (2,168,000)	Increase in bicycle share of trips within City of Paris from 1% in 2001 to 2.5% in 2007; 46% increase in bicycle trips from June to October 2007 after introduction of Velib' bicycle sharing program	<ul style="list-style-type: none"> • More than tripling of bike lane network from 122km in 1998 to 399km in 2007 • Tripling of bicycle parking on sidewalks from 2,200 in 2000 to 6,500 in 2007 • In 2007 started Velib', world's largest bicycle sharing program, now with over 20,000 short-term rental bikes • Introduction of 38 'quartiers verts', extensive traffic-calmed areas of the city with speed limits of 30km/hr or less, car-free zones, narrowed roadways and widened sidewalks, and six "civilized travel corridors" of restricted motor vehicle access • National Ministry of Education and insurance companies cooperate to provide extensive bicycling training courses in many schools with bicycle safety permits issued in 5th grade • Regular series of intensive bicycling training courses for adults offered twice a month in alternating arrondissements throughout Paris • Advance stop lines and priority traffic signals for cyclists at many intersections • Improved, uniform directional street signage for cyclists and special bicycle map and website to provide advice for best bicycle routes within Paris • Free program for engraving registration numbers on bikes to discourage theft • Elimination of free car parking throughout Paris 	City of Paris (2007 and 2009a, 2009b); Nadal (2007)
Barcelona, SP (1,606,000)	Bicycle share more than doubled in only two years: 0.75% of trips in 2005 to 1.76% in 2007	<ul style="list-style-type: none"> • Expansion of bike lane network from less than 10km in 1990 to 155km in 2008 (expanded by 28km 2007-2008) • Introduction of Bicing bicycle sharing program in 2005, since expanded to 6,000 short-term rental bikes in 2008, with over 400 bike rental stations • Extensive marketing in schools, combined with annual bike week with lots of special events, bicycle rides, informational workshops, etc. • Increased bike parking throughout city: 13,000 additional racks in 2007 and 2008, total of 20,392 in 2008 • Introduction of four traffic calmed zones with 30km/hr speed limits • Free bicycle registration and engraving of numbers on bikes to prevent theft 	Romero (2008)
Amsterdam, NL (735,000)	Bicycle share increased from 25% of trips in 1970 to 37% in 2005; 40% decline in serious injuries, 1985-2005	<ul style="list-style-type: none"> • Doubling in separate bicycling facilities between 1980 and 2007, with 450km in 2006, including construction of many bicycle bridges and short-cuts to create a complete network of separate bicycling facilities • Intersection improvements, advance stop lines and bike boxes, bicycle access lanes, priority traffic signals for cyclists • Bi-directional travel permitted for cyclists on many one-way streets • Extensive bike parking at all train stations; big expansion of guarded, sheltered bike parking • Ov-fiets (public transport bikes) for convenient, cheap short-term rental at key train stations • Car-free zones in city center; many residential streets are traffic calmed at 30km/hr, including some woonerfs with 7km/hr limit • Sharp reduction in car parking in city center • Mandatory bicycling education for all schoolchildren 	Fietsberaad (2006); Pucher and Buehler (2007)

Portland, OR (576,000)	Share of workers commuting by bicycle rose from 1.1% in 1990 to 1.8% in 2000 and 3.9% in 2005-07. Number of workers commuting by bicycle increased 329% since 1990, while the number of workers increased only 27%. The number of bicycles crossing four bridges into downtown increased 369% from 1992 to 2008. Number of reported crashes increased only 14% over same period.	<ul style="list-style-type: none"> • A 247% increase in the number of miles of bikeways (lanes, paths, and boulevards) from 79 in 1991 to 274 in 2008. • Colored bike lanes installed at several places of potential bicycle-motor vehicle conflict, assigning right of way to the cyclist. • Special bicycle-only signals at four difficult intersections. Loop detectors for bicycles at all actuated traffic signals on bicycle routes. Bike boxes at 10 intersections • Bicycle parking required in new development. City installs parking at other locations, including removing on-street parking for bicycle parking "corrals." • Bike racks on all transit buses and bikes allowed on trains. • First "Bike Sundays" held in 2008, closing city streets in one neighborhood to motor vehicles, similar to Ciclovias. • Education and marketing events conducted year-round and during SmartTrips program each summer. City-wide and neighborhood bicycle maps provided for free. 	US Census (2009), City of Portland (2008a and 2008b)
Copenhagen, DK (500,000)	Bicycle share increased from 25% of trips in 1998 to 38% in 2005 for 40+ age group; 70% increase in total bicycle trips 1970-2006 (36% of work trips in 2006); 60% decline in serious injuries 1995-2006	<ul style="list-style-type: none"> • Since 1970s, massive expansion of fully separate bike paths and cycletracks protected by curb from motor vehicle traffic (345km in 2004) plus 14km of unprotected bicycle lanes • Special intersection modifications: advance stop lines and bike boxes, bicycle access lanes, priority traffic signals for cyclists, bright blue marking of bike lanes crossing intersections • Green wave for cyclists, with traffic signals timed to cyclist speeds • Bi-directional travel permitted for cyclists on one-way streets cyclists • Guarded parking facilities increased from one in 1982 to 30 in 2006; plus 15 schools with guarded bike parking • Car-free zones and reduced car parking in city center; many residential areas are traffic calmed at 30k/hr or 20km/hr • Mandatory bicycling education for all schoolchildren • Over 20,000 bike parking spaces but not enough • Innovative bi-annual survey of cyclists to evaluate bicycling conditions • Pioneered city bikes program, which places 2,000 free bikes at 110 locations throughout the city; only small deposit required 	Pucher and Buehler (2007); Fietsberaad (2006)
Muenster, GER (278,000)	Bicycle share increased from 29% of trips in 1982 to 35% in 2001; one serious injury per 1.03 million bicycle trips in 2001	<ul style="list-style-type: none"> • More than doubled network of separate bike paths and lanes from 145km in 1975 to 320km in 2005, incl. 5km bicycle expressway and 12 bicycling streets • Large car-free zones in center; almost all residential streets traffic calmed at 30km/hr, incl. Home zones with 7km/hr; many contra-flow streets for cyclists • Intersections with advance stop lines and bike boxes for cyclists, advance green lights, bicycle turning lanes, and special bicycle access lanes as well as special colored marking of lanes crossing intersection • Bike station at the main train station and bus terminal, with parking for 3,500 bikes plus bike rentals, repairs, accessories, washing, and touring info. Also, large amounts of bike parking at all suburban rail stations throughout the city and region; bike station with 300 spaces in shopping district • Comprehensive system of directional signs • Mandatory bicycling education for all schoolchildren • Wide range of special bicycle rides, promotional events 	Pucher (1997); Pucher and Buehler (2007); Fietsberaad (2006); Boehme (2005); City of Muenster (2004)

Freiburg, GER (220,000)	Bicycle share increased from 15% of trips in 1982 to 27% in 2007; 204% growth in bicycle trips 1976-2007; one serious injury per 896,000 bicycle trips in 2006	<ul style="list-style-type: none"> Expanded separate bicycle paths and lanes from 29km in 1972 to 160km in 2007, plus 120km of bicycle paths through woods and agricultural areas; 2km of special bicycling streets; 60 contra-flow streets for cyclists Entire city center turned into car-free zone in 1970s; all residential streets (400km) traffic calmed, including 177 home zones with 7km/hr limit; plus two car-free residential neighborhoods Car parking restricted to fringe of city center; parking prices raised Tripling in bike parking between 1987 and 2009 (2200 to 6040 spaces), including full service bike station (with 1,000 parking spaces) at main train station plus 1,678 bike racks at train and bus stops City requires new developments to facilitate mixed-use, compact development that generates trips short enough to walk or bicycle Mandatory bicycling education for all schoolchildren 	Pucher (1997); Pucher and Clorer (1992); Buehler and Pucher (2009); Gutzmer (2006); Fietsberaad (2006);
Odense, DK (185,000)	Bicycle share increased from 23% of trips in 1994 to 25% in 2002; 80% increase in bicycle trips 1984-2002; 29% decline in injuries 1999-2004	<ul style="list-style-type: none"> National bicycling city pilot project, 1999-2002, financed huge range of innovative measures to promote bicycling and increase safety Design improvements to 500km of separate bike paths and lanes Many intersections were modified via advance stop lines and bike boxes for cyclists, advance green lights, bicycle turning lanes, and special bicycle access lanes as well as special blue marking of lanes where crossing intersection Improved signage, bicycle trip counters, bicycle air pumps, free bikes at work Green wave for cyclists, with traffic signals timed to cyclist speeds Improved maintenance of all bicycling facilities Expansion and improvement of bike parking, esp at train station Innovative internet bicycle route planning, also via mobile phones Car-free zones in center and traffic calming of residential neighborhoods at 30km/hr Mandatory bicycling education for all schoolchildren Wide range of promotional programs for all age groups, bicycling ambassador program, annual bicycle days, bicycling competitions, etc. 	Anderson (2005); City of Odense (2007); Fietsberaad (2006); Pucher and Buehler (2007)
Groningen, NL (181,000)	Stable 40% bicycle share of trips since 1990; 50% decline in serious injuries 1997-2005	<ul style="list-style-type: none"> Doubling in separate bicycling facilities between 1980 and 2006, with 220km in 2006, including construction of bicycle bridges and short-cuts to create a complete network of separate bicycling facilities Intersection modifications, advance stop lines and bike boxes, bicycle access lanes, priority traffic signals for cyclists; four-way green lights for cyclists at some intersections Bi-directional travel permitted for cyclists on one-way streets Increase in guarded parking facilities, from one in 1982 to 20 by 1995 and 30 in 2006; 15 schools with guarded bike parking Extensive bike parking at all train stations and key bus stops; roughly 7,000 bike parking spaces at main station Most residential streets are traffic calmed at 30km/hr, including many woonerfs with 7km/hr limit Car-free zones in several parts of the city center; sharp reduction in car parking Mandatory bicycling education for all schoolchildren 	Fietsberaad (2006); Pucher and Buehler (2007)

Boulder, CO (92,000)	The share of workers commuting by bicycle more than doubled, from 3.8% in 1980 to 8.8% in 2006; bicycle share of all trips (all purposes) rose from 8% in 1990 to 14% in 2006.	<ul style="list-style-type: none"> • Over 100 miles of multi-use pathways with 74 underpasses and 2 overpasses, plus 74 miles of on-street bike lanes and 195 miles of signed routes and streets with paved shoulders; 95% of major arterials have bike lanes or adjacent pathways. • City regulations requiring bike parking (at least 3 bike parking spaces or 10% of required off-street parking) • Bike to Work Day events since 2003; Safe Routes to School partnership with the local school district • Interactive bicycle routing website and an individualized marketing program • Coordination of transportation coordinators at local businesses • Ambassador Community Outreach Program focused on improving bicycle safety 	NRC (2007); Ratzel (2008); Roskowski and Ratzel (2008)
Davis, CA (63,000)	Drop in share of workers commuting by bicycle from 28% in 1980 to 14% in 2000; bicycle share of trips to campus by university students fell from 75% in 1970s to less than 50% in 2006	<ul style="list-style-type: none"> • The first city in the USA to install bike lanes, in the 1960s. • From 1970 to 2008, network expanded to over 50 miles of on-street bicycle lanes and 50 miles of off-street bicycle-pedestrian paths; including many bicycle tunnels and bridges • Intersection design improvements for cyclists, including bicycle-activated signals, special turn lanes, advance stop lines, etc. • During 1970s, city support for wide range of bicycling programs, including subsidized helmet programs, elementary school education programs, removal of abandoned bikes from racks, and strict enforcement of traffic laws • Gradual reduction in bicycling programs since mid 1980s 	Buehler and Handy (2008); Xing and Handy (2009); Tal and Handy (2008); Pucher et al. (1999)

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Pucher, Dill, and Handy, "International Review of Cycling Interventions," *Prev Med* 2010



Figure 1: Cycletrack in Copenhagen, separated from motor traffic by a curb, and in Paris, separated by curb and parking (photos by P. Berkeley and J. Dill)



Figure 2: Bicycle boulevard in Portland, OR with speed hump and traffic circle to slow and divert motor vehicles (photo by J. Dill)



Figure 3: Bike box in Portland, OR (photo by N. McNeil)



Figure 4: Contraflow lane in Copenhagen (photo by J. Dill)



Figure 5: Shared lane marking in Columbia, MO (photo by J. Dill)



Figure 6: Bike station in Muenster, Germany (photo by P. Berkeley)

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