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Review

Infrastructure, programs, and policies to increase bicycling: An international review

John Pucher [a,*], Jennifer Dill [b], Susan Handy [c]

[a] Bloustein School of Planning and Public Policy, Rutgers University, 33 Livingston Avenue, New Brunswick, NJ 08901, USA
[b] Toulan School of Urban Studies and Planning, Portland State University, PO Box 751, Portland, OR 97207, USA
[c] Department of Environmental Science and Policy, University of California, 1 Shields Avenue, Davis, CA 95616, USA

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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 14 case study cities that adopted multiple interventions.

Results. Many studies show positive associations between specific interventions and levels of bicycling. The 14 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, supportive land use planning, and restrictions on car use.

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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; 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).

* Corresponding author.
E-mail address: pucher@rutgers.edu (J. Pucher).

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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, 2008; USDOT, 1994, 2004; WHO, 2002a,b).

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 threefold: (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.

An extensive and rapidly growing literature 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, whereas 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.

Methods

We first developed a list of interventions 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. The initial list was reviewed by other experts and practitioners and expanded. Although 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, which 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 information. We also contacted bicycle researchers and practitioners in the US, 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. (2004). Combined measures were often used in studies evaluating interventions such as paths and trails, which accommodate both walking and bicycling. 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. Although real or perceived safety levels likely influence levels of bicycling, these studies were not systematically included in this review. Some examples, however, 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 studies measure actual behavior, either through self-report (e.g., surveys) or more objective means (e.g., automatic counters or global positioning systems [GPS]). Stated preference studies measure people's opinions or intended behaviors. They are often perceived as being less reliable than revealed preference studies. Stated preference methods are often used to test interventions (or packages of interventions) that do not currently exist and, therefore, could not be recorded by revealed preference methods. Sophisticated stated preference 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 selected only 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 sources that included evidence of the effect of specific interventions on bicycling, of which 65 appeared in peer-reviewed publications (see Tables 1–4). That number 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 to separate cyclists from motor vehicles. (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 "cycle-tracks," which function like a bike lane but have greater physical separation from motor vehicles (Fig. 1). Contraflow lanes permit cyclists to ride against motor vehicle traffic on one-way streets (Fig. 2). Forty studies attempted to evaluate the effect or value of bike lanes and/or separate 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 they yielded 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, whereas the individual-level studies had mixed findings. A cross-sectional study at the city level of over 40 US cities found that each additional mile of bike lane per square mile was associated with an increase of approximately one percentage point in the share of workers regularly commuting by bicycle (Dill and Carr, 2003). A study of Seattle, Washington 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).

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., 2009a). 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 US, bicycle lanes are usually designated by 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 US cities, though to varying degrees. Data for 43 of the 50 largest cities in the US found from 0 to 1.5 linear miles of bike lanes per square mile (Dill and Carr, 2003).	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). 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 *perception* 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). 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, in press; 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, in press; 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., 2009b). 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). 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).
Two-way travel on one-way streets	**Contraflow bike lanes** allow bicyclists to travel in the opposite direction on one-way streets (Fig. 2). **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.	Contraflow lanes and similar treatments are common in many European cities, usually on urban residential streets with low traffic speeds. They are rare in the US (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 (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)	Off-street paths are common in US cities, though the number of miles is often limited. A survey of 50 large cities found a range of <0.1 to >3.0 linear miles of paths per square mile (Thunderhead Alliance, 2007). Most paths in the US are for mixed travel, though some have lane markings to separate cyclists from	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 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

	recreational facilities (AASHTO, 1999). Paths can be mixed use (including pedestrians, rollerbladers, etc.) or limited to cyclists.	pedestrians and other users.	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 On-road bicycle lanes section, 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 Goulias, in press; 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 US 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., 2009a). 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 (Fig. 3)	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 speed bumps, diverters and traffic circles.	Bicycle boulevards are much less common in the US 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) (Fig. 1)	Cycletracks are similar to bike lanes, but are physically more separated from motor vehicles, for example with a curb, vehicle parking, or other barriers (Fig. 1). They are often wider than a typical US 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 US (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 *rate* 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 US. Some US 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 (also known as sharrows) (Fig. 4)	Shared lane markings are used in lanes shared by motor vehicles and bicycles to alert drivers to the potential presence of cyclists and to show cyclists where to ride.	Shared lane markings are rare in the US, 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) (Fig. 5)	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 on 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 US, though at least eight US 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 advanced stop lines 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 US. 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 potential harms (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 US 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).

(continued on next page)

Table 1 *(continued)*

Measure	Description	Examples and extent of implementation	Measured effects on amount of bicycling
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 US cities.	No studies 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 US. We could not identify any examples in the US of right-turn shortcuts specifically for cyclists that were not already separate paths.	No studies 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 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 (ITE) published a report on the state of traffic calming practice in the US (Institute of Transportation Engineers, 1999). Traffic calming programs for local streets are common throughout the US, 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, Massachusetts 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, 1989). 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 UK, and other parts of Europe. The UK Department for Transport promotes the home zone concept. The concept has not been adopted in the US, though examples of streets that follow the principles of home zones can be found.	An evaluation of nine home zone schemes in the UK 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 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 US. 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 US 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 people arriving 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, or 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, and 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 US and by 10 states as of 2007 (Thunderhead Alliance, 2007). The US Congress is considering a federal complete streets policy. The number of projects built according to complete streets principles is growing.	No studies on the impact of complete streets policies or projects on bicycling levels are publicly available at this time.

AASHTO, American Association of State Highway and Transportation Officials; RP, revealed preference; SP, stated preference.

Table 2
Bike parking and end-of-trip facilities.

Measure	Description	Examples and extent of implementation	Measured effects on bicycling
Bike parking	General	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 2005, 2007, 2008, and in press; Fietsberaad, 2006; Litman, 2009; Thunderhead Alliance, 2007). Incomplete statistics generally include public bike parking but not privately provided parking at residences, workplaces, and commercial buildings, or at schools and universities. 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 (US), BREEAM (UK); CASBEE (Japan); and Green Star (Australia) (Litman, 2009; Kessler, 2008; US Green Building Council, 2005; Pucher, 2008).	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 in-route bicycling time. 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.
	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 a 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 and in outdoor parking 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; Hunt and Abraham (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 (Fig. 6)	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 in press; 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 located 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).	Although no studies have measured impacts of bike stations on bicycling, they are presumably positive, because such bike stations are generally well utilized due to security, convenience, and wide range of services offered.

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. Only four studies examined bicycle boulevards and traffic-protected cycletracks, types of roadway infrastructure less common in the US. The findings generally showed a positive association between these facilities and bicycling, though without good estimates of the quantitative effects on actual bicycling rates.

Bicycle boulevards employ techniques similar to those for traffic calming streets to reduce the number and speed of cars (Fig. 3). 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 (see Table 1 for definitions and more detail).

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 although 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 on-street lanes to bike paths. These cyclists appear less willing to trade off the additional time required to access 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 (Fig. 4), and bike boxes (also known as advanced stop lines; Fig. 5). 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. Studies that included surveys of cyclists

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 public transport (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 (2003), Pucher and Buehler (in press), and Netherlands Ministry of Transport (2009) found that provision of good bike parking at PT 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, in press; Thunderhead Alliance, 2007).	Most studies focus on impacts of bike racks on bus use, and find positive impacts, generating more revenues than cost 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, in press; 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, because it helps cyclists cover long portions of trip by PT while using their bikes to reach PT stops and access destinations (USDOT, 1998; TRB, 2005; Pucher and Buehler, in press).
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.

PT, public transport.

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 consensus on the need to provide good bike parking for cyclists—especially secure, sheltered parking to prevent theft and to 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 providing 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 services, including storage, rental, repair, and showers (Fig. 6). No comprehensive statistics on bike parking supply for any country were found, 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, because 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 stated preference survey data—Wardman et al. (2007) estimated statistically significant impacts of parking and showers on bicycling levels. Compared to a baseline level of 5.8% of work trips by bicycle, providing 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 integrating 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 found 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 (which has most of the world's rack-equipped buses) 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.

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 UK.	Programs are common in the US 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 UK 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 US led to a 39% increase in walking and bicycling combined (Shoup, 1997). In a study of the “Mobility Management” policy in the Netherlands, eight 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 three 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 (also known asTravelSmart and SmartTrips)	Comprehensive marketing programs aimed at individuals in a neighborhood, school, or worksite. 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 US cities, though the number is increasing. More recent programs in US cities are branded under different names, such at SmartTrips in Portland, OR.	A review of before-and-after evaluations found an increase in bicycle trips in 10 of 11 Australian neighborhood programs, as well as increases in bicycling in 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 US, the increase ranged from one to two percentage points (e.g., from 3% to 4% of all trips); in the other cases, the increase 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 in 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 1,035 participating cities and 428 supporting cities in 2003 (Cairns et al., 2004). Programs are more common in Europe than in the US.	Evaluations of media campaigns tend to focus on marketing-style outcomes— for example, how many people noticed a campaign, what they remember from it—rather than change in travel behavior. Awareness of travel behavior campaigns range from 17% to 76%; 20% to 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 US 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 SRTS programs on bicycling. A study in Marin County, CA, one of the earliest programs in the US, found a 114% increase in the number of students bicycling to school (Staunton et al., 2003). An examination of infrastructure projects at 10 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, giveaways, contests, and other activities.	Bike-to-Work events are popular in metropolitan areas in the US. The number of programs and the numbers of participants in individual programs have increased.	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, rollerbladers, and cyclists.	These events started in the 1960s in San Francisco, Seattle, and Sao Paolo, and gradually spread throughout the Americas (Sarmiento et al., in press). Since 2000, growth has been rapid: 25 new programs have started, for a total of 38 cities with ongoing programs in the Americas. South America	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., in press). Using cross-sectional data, Cervero et al. (2009) found that proximity to ciclovia bikeways is associated with higher levels of ciclovia use. Also using cross-sectional data, Gomez et al. (2005) found an association between recreational riding on ciclovias and utilitarian cycling such as bike trips to

(continued on next page)

Table 4 *(continued)*

Measure	Description	Examples and extent of implementation	Measured effects on amount of bicycling
General Travel Programs			
Ciclovias (or "ciclovias-recreativa")		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.	work. Bogota has the world's largest ciclovia, with 123 km of streets closed to cars and 700,000 to 1 million participants. Bogota's bicycle mode share has tripled as the popularity of the ciclovia has grown, but the scale of this ciclovia 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 US. 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, giveaway 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 designed to increase bicycling skills and knowledge of bicycling laws.	In the US, 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 US (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, and 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 and 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 made 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), and 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 giveaway programs, loaner programs, fleet programs, and service and repair programs.	No inventory of such programs is available.	In the BikeBus'ters pilot project in Arhus, Denmark in 1995–1996, 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 ~15% to ~60% (Bunde, 1997; Overgaard-Madsen et al., in press). 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 US, 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 (Bicycle Helmet Safety Institute (BHSI), 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., reduce 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 UK has promoted 20 mph 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). Widespread automobile speed limits in Hilden, Germany led to a significant increase in bicycling (Bauman et al., 2008). Studies in the UK 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).

BWD, Bike-to-Work Day(s).

Fig. 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).

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, although 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

Fig. 2. Contraflow lane in Copenhagen (photo by J. Dill).

Fig. 3. Bicycle boulevard in Portland, OR with speed hump and traffic circle to slow and divert motor vehicles (photo by J. Dill).

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, Australia, 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., in press). One study in Bogota found that riding in ciclovias was associated with more utilitarian cycling as well (Gomez et al., 2005).

Fig. 4. Shared lane marking in Columbia, MO (photo by J. Dill).

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 bicycling has increased in cities that have implemented bike sharing programs. The proportion 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 proportion of trips 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

Fig. 5. Bike box in Portland, OR (photo by N. McNeil).

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 in traffic-calmed residential neighborhoods. 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 14 cities that 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 5 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

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

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%) and 12% reduction in serious bicyclist injuries over same period. After implementation of congestion charging in 2003, average annual growth of 17% in bicycle trips between 2003 and 2006, and increase in bicycle share of all trips (all trip purposes) from 1.2% to 1.6%.	• 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, contraflow bike lanes, and mixed-use pedestrian/bike paths: 4,000 km total length, of which 550 km are special facilities of some sort, but not usually-separated from traffic • Traffic calming of some residential neighborhoods through roadway design modifications and 20 mph 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 Cycling 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, between 7:00 and 18:30 on workdays, raised to £8 in Feb 2005; expansion of charging zone in Feb 2007, 7:00–18:00	Transport for London (2004b, 2008a,b)
Bogota, COL (7,881,000)	Increase in bicycling share of trips from 0.8% in 1995 to 3.2% in 2003; participation in ciclovia grew from 5,000 in 1974 to over 400,000 in 2005.	• From 1998 to 2000, 344 km of separate bike paths built, connecting to public transport and major destinations • Ciclovia: 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 placa") • 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 toward cyclists and pedestrians	Parra et al. (2007); IDRD (2004); IDU (2009); Montezuma (2005); Despascio (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.	• Network of separate bicycling facilities tripled from 271 km in 1970 to 920 km in 2008; also 70 km of bus-bike lanes and 100 km of shared-use paths • 3,800 km of residential streets (72% of all roads) are traffic calmed at 30 km/hr or less, including many home zones with 7 km/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.	• Bike lane network more than tripled from 122 km in 1998 to 399 km in 2007 • Tripling of bicycle parking on sidewalks from 2,200 in 2000 to 6,500 in 2007 • Started Velib' in 2007, world's largest bicycle sharing program, now with over 20,000 short-term rental bikes • Introduction of 38 "quartiers verts" (green zones), extensive traffic-calmed areas of the city with speed limits of 30 km/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, 2009a, and 2009b); Nadal (2007)
Barcelona, SP	Bicycle share more than doubled in only two years:	• Expansion of bike lane network from less than 10 km in 1990 to 155 km in 2008 (expanded by 28 km,	Romero (2008)

(1,606,000)	0.75% of trips in 2005 to 1.76% in 2007.	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 30 km/hr speed limits • Free bicycle registration and engraving of numbers on bikes to prevent theft	
Amsterdam, NL (735,000)	Bicycle share increased from 25% of trips in 1970 to 37% in 2005; 40% decline in serious injuries, 1985–2005.	• Doubling of separate bicycling facilities between 1980 and 2007, with 450 km 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 30 km/hr, including some woonerfs ("living yards") with 7 km/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 6.0% in 2008. Number of workers commuting by bicycle increased 608% from 1990 to 2008, while the number of workers increased only 36%. 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.	• 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.	• Since 1970s, massive expansion of fully separate bike paths and cycletracks protected by curb from motor vehicle traffic (345 km in 2004) plus 14 km 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 • Guarded parking facilities increased from one in 1982 to 30 in 2006; 15 schools had guarded bike parking • Car-free zones and reduced car parking in city center; many residential areas are traffic calmed at 30 km/hr or 20 km/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 of trips increased from 29% in 1982 to 35% in 2001; one serious injury per 1.03 million bicycle trips in 2001.	• More than doubled network of separate bike paths and lanes from 145 km in 1975 to 320 km in 2005, including 5 km bicycle expressway and 12 bicycling streets • Large car-free zones in city center; almost all residential streets traffic calmed at 30 km/hr, including home zones calmed to 7 km/hr; many contraflow 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 information. 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)

(continued on next page)

Table 5 *(continued)*

City (population)	Trends in bicycling levels and safety	Bicycling infrastructure and programs	References
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.	• Expanded separate bicycle paths and lanes from 29 km in 1972 to 160 km in 2007, plus 120 km of bicycle paths through woods and agricultural areas; 2 km of special bicycling streets; 60 contraflow streets for cyclists • Entire city center turned into car-free zone in 1970s; all residential streets (400 km) traffic calmed, including 177 home zones with 7 km/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 (2,200 to 6,040 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 of trips increased from 23% in 1994 to 25% in 2002; 80% increase in bicycle trips 1984–2002; 29% decline in injuries 1999–2004.	• National bicycling city pilot project, 1999–2002, financed huge range of innovative measures to promote bicycling and increase safety • Design improvements to 500 km of separate bike paths and lanes • Many intersections 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, especially at main train station • Innovative Internet bicycle route planning, also via mobile phones • Car-free zones in city center and traffic calming of residential neighborhoods at 30 km/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.	Andersen (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.	• Separate bicycling facilities doubled to 220 km between 1980 and 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 30 km/hr, including many woonerfs with 7 km/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)	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.	• 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 off-street parking) • Bike-to-Work Day events since 2003; Safe Routes to School partnership with 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.	• First city in the US 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)

doubled between 2000 and 2008, while bicyclist injuries fell by 12% over the same period. 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 aged 40 years and older. Yet, there was a 60% decline in serious injuries. Between 1990 and 2008, the number of workers commuting mainly by bicycle in Portland, Oregon increased over 600%, while the share of workers commuting by bicycle rose from 1.1% to 6.0%.

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%). These data suggest that it may be difficult to increase bicycling beyond 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 US 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 14 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 central London (assessing a daily fee for entering a 21-sq.km zone) 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,b).

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 long-standing 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, such as 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 in affecting bicycling levels than explicitly pro-bicycle policies. 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, which are 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 US 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, the studies 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 levels of bicycling 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 non-cyclists in cities with little bicycling. Research has found that non-cyclists who are surrounded by other cyclists may be more likely to have contemplated cycling and thus more responsive to policy interventions (Gatersleben and Appleton, 2007). 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, 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 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, these groups should 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 multifaceted, 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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