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Review Essay

The effect of infrastructural changes in the built environment on physical activity, active transportation and sedentary behavior – A systematic review

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ABSTRACT

This systematic review examined the effect of built environment infrastructural changes (BEICs) on physical activity (PA), active transportation (AT) and sedentary behavior (SB). A literature search resulted in nineteen eligible articles. On- and off-road bicycling and/or walking trails resulted in inconsistent effects on overall PA and walking, and in predominantly positive effects on bicycling. More extensive BEICs led to mixed results, with mainly non-significant effects. However, positive effects on bicycling were found for people living closer to BEICs. None of the studies assessed SB. Improved understanding of the potential of BEICs to increase PA levels and decrease SB at population level asks for more high-quality, in-depth research, that takes into account the broader system.

1. Introduction

In recent decades, the prevalence of obesity has increased in most countries and regions of the world (Wang et al., 2011). Public health experts agree that the rapid rise in obesity cannot be explained by changes in genes, biology and psychology at the individual level alone. The explanation should also be sought in broader environmental, policy and societal changes (Kaplan et al., 2000; Sallis and Glanz, 2009). As the choices people make are partially shaped by the environments in which they live, efforts to reduce obesity, type II diabetes and cardiovascular diseases by interventions at individual level need to be supported and augmented by a whole-system response that includes upstream health policies, infrastructural changes and legislation (Lakerveld and Mackenbach, 2017; Rutter et al., 2017). Hence, researchers and policy makers are increasingly interested in environmental and policy interventions as strategies for population-wide improvements in physical activity (PA) and eating habits, in order to reduce and prevent obesity and associated non-communicable diseases (Chaix, 2009; Sallis and Glanz, 2009).

In recent years, a broad range of environmental interventions have been implemented to improve PA levels, for example by installing outdoor exercise equipment, reconstructing playgrounds and increasing the amount of open green space (Cohen et al., 2012; Veitch et al., 2012). In addition, a growing number of built environment infrastructural changes (BEICs) aim to promote active transportation (AT) – walking and bicycling for transportation. An example of a BEIC is the implementation of a walking and bicycling trail, aiming to replace passive, sedentary, transportations by AT (Evenson et al., 2005). BEICs have the potential to promote and sustain behavioral changes over a longer period of time (Davies et al., 2011; Sallis and Glanz, 2009). The built environment (BE) not only promotes or inhibits PA and AT, but can also play a role in reducing sedentary behavior (SB). The SOS (Systems of Sedentary behavior) framework emphasizes the role of the built and natural environments in interrupting sedentary time (Chastin et al., 2016), which is crucial in order to reverse the global trend toward increased sedentary time (Ng and Popkin, 2012) and physical inactivity (Kohl et al., 2012). Previous studies found that presence and proximity of green spaces is negatively correlated with SB (O'donoghue et al., 2016). Also, BEICs aiming to promote AT might evoke a modal shift from sedentary motorized transportation to AT, leading to both a decrease in SB and an increase in PA.

Cross-sectional studies have found positive associations between the BE and PA, mental health, physical health and well-being (e.g., Gao et al., 2016; Sallis et al., 2016; Gubbels et al., 2016), but longitudinal and experimental studies are necessary to detect causal relationships between the BE and health outcomes. In general, it is hardly possible to perform randomized controlled trials to evaluate large-scale policy and environmental interventions, as researchers usually cannot influence such interventions and participants cannot be randomly assigned to intervention or control sites. Natural experimental studies might help to overcome these problems. In this type of studies, the exposure to the event or intervention of interest has not been manipulated by the researcher (Craig et al., 2012). In the literature, the terms "natural experiments" and "quasi-experiments" are inconsistently used. In both

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types of experiments, researchers cannot randomly assign participants to an intervention or control condition. Typically, in quasi-experiments researchers have a certain degree of control over the intervention, while the intervention or event of a natural experiment occurs outside the reach of researchers (Cook et al., 2002).

Previous systematic reviews evaluated the effects of several types of changes in the BE on PA levels and found that infrastructural interventions targeting AT in particular can lead to increased PA (Mayne et al., 2015; Smith et al., 2017). One recent systematic review concluded that the evidence on the effect of the BE on PA is not strong enough to draw conclusions (MacMillan et al., 2018). However, these reviews included a broad range of BE interventions, such as park improvements, infrastructural changes and changes to the public transport infrastructure. The heterogeneity of these interventions makes it difficult to evaluate the actual effect on PA and/or AT. Focusing on BEICs aiming to promote PA and/or AT may lead to more clarity regarding the effectiveness of this specific type of interventions. In addition, previous systematic reviews included participants in all age ranges, while barriers and facilitators to engage in PA and/or AT are different for different age groups. Also, none of the previous reviews searched for studies reporting SB.

The current review builds on the main outcomes of Mayne's and Smith's review by assessing the specific effectiveness of different types of BEICs that aim the promotion of PA and/or AT to clarify the effectiveness of this type of interventions in adults. Therefore, the aim of this systematic review is to update and specify the evidence in this field of research by reviewing experimental studies that have examined the effects of different types of infrastructural interventions on PA, AT and SB in adults.

2. Methods

2.1. Search and selection procedure

A literature search was conducted using PubMed and Web of Science to identify articles examining the effects of BEICs on PA, AT and/or SB, published up to February 2018. The following keywords/terms were included in the search: adult AND built environment OR changes in built environment OR infrastructure OR changes in infrastructure OR path OR trail OR bicycle path OR footpath AND motor activity [MeSH] OR physical activity OR active travel* OR active transport*, OR walking OR bicycling OR exercise OR sport OR sedentary OR sedentary behavior OR natural experiment* OR quasi experiment*. Searches were not restricted by date of publication.

Studies were eligible if: (1) they were a quasi- or natural experiment and had a pre-post design, (2) the BEIC directly targeted the increase of AT and/or transport-related PA (3) PA and/or AT and/or SB was reported, (4) these were assessed in adults, and (5) the articles were written in English. Studies were excluded if they (1) examined BEICs that were not directly aimed to increase transport-related PA and/or AT, such as the implementation of playgrounds, parks or public transit, the placement of fitness equipment, or other non-infrastructural interventions, (2) evaluated health promotion programs or behavior change programs, (3) concerned qualitative research, systematic reviews, conference proceedings or grey literature (4) included children or adolescents younger than 18 years. After duplicates had been removed, titles of all records were screened independently by two reviewers (XXX, XXX). Articles selected by one or both researchers were subjected to abstract screening. Again, both reviewers (XXX, XXX) performed this screening independently, and ineligible studies were removed from the sample. Disagreements between reviewers about eligibility for full-text assessment were resolved by discussion, which was necessary in five cases. The full texts of the remaining articles were assessed by one researcher (XXX). Reference lists from selected studies were hand-searched for additional articles not retrieved by the electronic search.

One reviewer (XXX) extracted the following information from each included study: author(s), publication year, study location, description of intervention, study population, study design, control sites, PA outcome measures, AT outcome measures, measuring methods, timing of the measurements and main findings.

2.2. Risk of bias assessment

The quality of the included studies was assessed using the adapted version of A Cochrane Risk of Bias Assessment Tool: for Non-Randomized Studies of Interventions (ACROBAT-NRSI), by following the detailed scoring protocol. The adapted version of the ACROBAT-NRSI, including signaling questions, was constructed and published by Benton et al. (2016). Aspects which were adapted are specific for the field of natural experiments and quasi-experiments, such as control site selection and measuring exposure to intervention. In addition, the assessment of internal validity was supplemented with the assessment of two other types of validity (statistical conclusion validity and construct validity). The following domains of bias were included in the risk of bias assessment: Bias due to confounding, bias in selection of participants into the study, bias in measurement of interventions, bias due to departures from intended interventions, bias due to missing data, bias in measurement outcome and bias in the selection of reported results (Table 1). We were aware that the ACROBAT-NRSI might set the bar of methodological acceptability too high, leading to downgrading of evidence from natural experiments (Humphreys et al., 2017), but nevertheless considered this tool suitable for comparing the included studies with each other, rather than judging them by the absolute score. A random 33% sample of the included studies were assessed for the risk of bias assessment by two researchers. The results of the assessments were compared and discussed until consensus was reached. The remaining included studies were assessed accordingly by one researcher (XXX).

3. Results

3.1. Study selection

Fig. 1 shows the numbers of publications identified, screened, assessed for eligibility and included. In total, 4163 articles were identified through database searching and checking reference lists. After removing duplicates, 3265 publications remained in the sample, 3170 of which were excluded after title screening. Ninety-five abstracts were reviewed, 47 of which were excluded (list provided in Supplementary file 1). The full texts of the remaining 48 articles were assessed, and 19 articles were included in this systematic review.

3.2. Risk of bias

The risk of bias in the included articles varied from moderate (Goodman et al., 2014; Heinen et al., 2017; Panter and Ogilvie, 2017) to serious (Crane et al., 2017; Heesch et al., 2016; Heinen et al., 2015; Panter et al., 2016; Parker et al., 2013; Rissel et al., 2015; Song et al., 2017) and critical (Dill et al., 2014; Evenson et al., 2005; Fitzhugh et al., 2010; Hirsch et al., 2017; Krizek et al., 2009; Parker et al., 2011; Pazin et al., 2016; West and Shores, 2011, 2015) (Table 1). None of the included articles scored low for risk of bias. Risk of bias was lowest in the domains of "bias due to departures from intended interventions" and "bias due to missing data". Risk of bias was highest in the domains of "bias in the selection of participants into the study", "bias in measurement outcome" and "bias in the selection of reported results". A fully justified sample size calculation was missing for most of the included studies, except for Pazin et al. (2016). Outcome measurements were assessed subjectively in the vast majority of the studies. Only Goodman et al. (2014) and Crane et al. (2017) reported the results of more than one follow-up. Study protocols were published for three out of fourteen unique interventions (Rissel et al., 2013; Ogilvie et al., 2010, 2012), making it difficult to judge whether analyses and outcome

Table 1
Results risk of bias assessment.

	Bias due to confounding	Bias in selection of participants into the study	Bias in measurement of interventions	Bias due to departures from intended interventions	Bias due to missing data	Bias in measurement outcome	Bias in the selection of reported results	Total
Dill et al. (2014)	Moderate	Moderate	Serious	Critical	Serious	Moderate	Moderate	**Critical**
Evenson et al. (2005)	Critical	Moderate	Moderate	Serious	Moderate	Serious	Critical	**Critical**
Fitzhugh et al. (2010)	Serious	Critical	Moderate	Low	Low	Moderate	Moderate	**Critical**
Heesch et al. (2016)	Moderate	Serious	Serious	Low	Moderate	Serious	Serious	**Serious**
Rissel et al. (2015)	Moderate	Serious	Moderate	Low	Low	Serious	Serious	**Serious**
Crane et al. (2017)	Moderate	Serious	Moderate	Low	Moderate	Serious	Serious	**Serious**
Parker et al. (2011)	Serious	Critical	Serious	Low	Low	Serious	Moderate	**Critical**
Parker et al. (2013)	Serious	Serious	Moderate	Low	Low	Serious	Serious	**Serious**
Pazin et al. (2016)	Moderate	Moderate	Moderate	Moderate	Low	Critical	Critical	**Critical**
West et al. (2011)	Critical	Serious	Moderate	Serious	Moderate	Serious	Critical	**Critical**
West et al. (2015)	Moderate	Serious	Moderate	Moderate	Low	Critical	Critical	**Critical**
Goodman et al. (2014)	Moderate	Moderate	Low	Low	Low	Moderate	Moderate	**Moderate**
Song et al. (2017)	Moderate	Moderate	Low	Low	Low	Moderate	Serious	**Serious**
Panter et al. (2017)	Moderate	Moderate	Low	Low	Low	Moderate	Moderate	**Moderate**
Heinen et al. (2015)	Moderate	Moderate	Moderate	Low	Low	Moderate	Critical	**Serious**
Heinen et al. (2017)	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate	**Moderate**
Panter et al. (2016)	Moderate	Serious	Serious	Serious	Low	Moderate	Moderate	**Serious**
Hirsch et al. (2017)	Serious	Critical	Moderate	Moderate	N.I.	Serious	Serious	**Critical**
Krizek et al. (2009)	Critical	Serious	Serious	Moderate	N.I.	Serious	Moderate	**Critical**

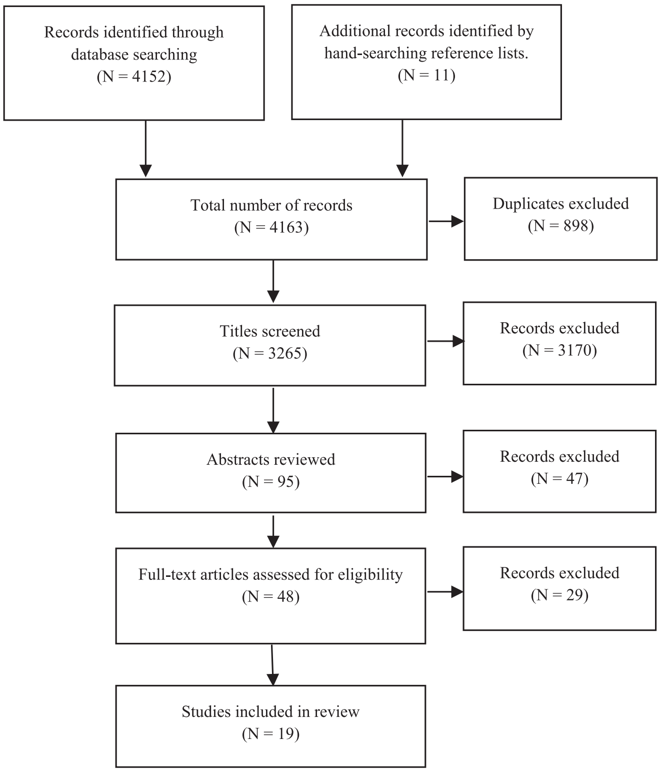

Fig. 1. Flowchart of article selection.

measures used were pre-specified or were selected on the basis of the results from multiple outcome measures, multiple analyses or the use of multiple subgroups.

3.3. Study characteristics

The study characteristics of the 19 included studies are presented in Table 2. In total, fourteen unique BEICs were evaluated. The studies were divided into two categories, based on the magnitude of the BEICs. A distinction was made between single on- and off-road bicycling and/or walking trails and trails that were part of more extensive BEICs that affected the total infrastructural system. Eleven studies were assigned to the category on- and off-road walking and/or bicycling trails (Crane et al., 2017; Dill et al., 2014; Evenson et al., 2005; Fitzhugh et al., 2010; Heesch et al., 2016; Parker et al., 2011, 2013; Pazin et al., 2016; Rissel et al., 2015; West et al., 2011, 2015). Eight studies were assigned to the category of BEICs affecting total infrastructural system (Goodman et al., 2014; Heinen et al., 2015, 2017; Song et al., 2017; Panter et al., 2016; Panter and Ogilvie, 2017; Krizek et al., 2009; Hirsch et al., 2017). Three BEICs were evaluated in multiple articles; the Connect2 project, UK (Goodman et al., 2014; Panter and Ogilvie, 2017; Song et al., 2017), the construction of a 25 km off-road guideway for buses with parallel walking and/or bicycling path in Cambridgeshire, UK (Heinen et al., 2015, 2017; Panter et al., 2016) and the implementation of 2.4 km cycling path in Sydney, Australia (Crane et al., 2017; Rissel et al., 2015). Moreover, in three cases BEICs in the same city and context were evaluated in two separate studies (Parker et al., 2011, 2013; West et al., 2011, 2015; Krizek et al., 2009; Hirsch et al., 2017). These studies were marked as unique interventions since they evaluated unique BEICs during another time path.

Sample sizes of included studies ranged from 169 to 1906 participants (West et al., 2011; Song et al., 2017, respectively) of which two studies (Parker et al., 2011, 2013) included both children and adults in their systematic observations. We chose to keep these articles in our review, as the studies reported that very few children were observed. Five studies did not provide the exact number of participants, as a result of the study design (Fitzhugh et al., 2010; Hirsch et al., 2017; Krizek et al., 2009; Parker et al., 2011, 2013).

The BEICs were completed between 2000–2007 and 2014, baseline measurements were performed between 2000 and 2013 and follow-up measurements took place between 2002 and 2014. Follow-up measurements were executed between two and thirty months after opening of the intervention. The time between the openings of the intervention varied between and within studies. Six articles evaluating four unique interventions had a twelve-month period or longer between initial opening of the intervention site and follow-up measurement for all participants (Crane et al., 2017; Fitzhugh et al., 2010; Heinen et al., 2015, 2017; Panter et al., 2016; Pazin et al., 2016). In two studies, the time between the opening of the intervention and follow-up measurement was more than twelve months for at least a part of the sample (7–21 months and 9–14 months, Goodman et al., 2014; Panter et al., 2016, respectively). For the studies of Hirsch et al. (2017) and Krizek et al. (2009), exact opening dates of the BEICs were not stated, but given the amount of time between baseline and follow-up − 10 years – we assumed that the follow-up measurement was performed more than twelve months after the implementation of the BEICs.

Outcome measures included time spent walking, bicycling, moderate physical activity (MPA), vigorous physical activity (VPA), moderate-to-vigorous physical activity (MVPA), total PA, recreational PA, recreational MVPA, recreational PA near home, number of bicyclists and walkers, time spent walking on the commute, time spent cycling on the commute, changes in commute mode share, journey stages in AT, and numbers of bicycle and walking trips.

Outcome measures were divided into five categories; overall PA (MPA, VPA, MVPA, total PA, recreational PA, recreational MVPA, recreational PA near home), walking (time spent walking in leisure time or commuting, walking trips, number of walkers), bicycling (time spent cycling in leisure time or commuting, bicycling trips, number of cyclists), walking and bicycling (active commute mode share, active transport/ active commuting, walking and bicycling on the commute) and SB (time spent sitting). Seven studies used objective measures to assess PA and AT, three of which used direct observation (Fitzhugh et al., 2010; Parker et al., 2011, 2013). Two studies evaluating one intervention used electronic counters to count bikes (Crane et al., 2017; Rissel et al., 2015). One used accelerometry and a Global Positioning System (GPS) (Dill et al., 2014) and one used a mobile phone application (Heesch et al., 2016). Subjective measurements included telephone surveys, questionnaires, 7-day commute travel diaries and 7-day recall instruments.

3.4. Results per type of intervention

Table 3 describes the effects of BEICs on PA, walking, cycling and SB and the effect of proximity to the intervention on outcome measures, per intervention type. Key findings are presented in Table 4.

3.4.1. On- and off-road bicycle and/or walking trails

Eleven studies evaluated the effects of on- and off-road bicycle and/or walking trails on overall PA, walking and bicycling. The effects of on- and off-road bicycle and/or walking trails on overall PA were mixed. Two studies reported increases in PA (West et al., 2011; Fitzhugh et al., 2010) and two reported no significant changes (Dill et al., 2014; West et al., 2015). One study reported decreases in VPA, but no changes in MVPA (Evenson et al., 2005). Regarding walking, the results were mixed as well. Two studies reported increases in walking (West et al., 2011; Fitzhugh et al., 2010) and three reported no significant changes (Dill et al., 2014; West et al., 2015; Evenson et al., 2005). Eight studies reported bicycling of which the majority reported increases in at least one outcome measure (Crane et al., 2017; Heesch et al., 2016; Parker et al., 2011, 2013; Fitzhugh et al., 2010; Rissel et al., 2015). One study reported decreases in bicycling (Dill et al., 2014). None of the studies assessed SB.

Table 2
Study characteristics of included studies.

Author, year	Study location	Description BEICs	Study population	Study design	Control sites/exposure groups	Outcome measures	Measurement method	Timing follow-up
On- and –off-road walking and/or bicycling trails								
Dill et al. (2014)	Portland, Oregon, USA	Installation of eight 0.9–4.2 mile long bicycle boulevards (streets with low motorized traffic volumes and speeds, designated and designed to give bicycle travel priority)	293 adults with children from Family Activity Study. Divided into treatment (N = 154) and control (N = 139) groups. Able to ride a bicycle, access to a working bicycle	Natural experiment; longitudinal panel design with control group	11 control street segments (1.0 to 5.7 miles long), similar in urban form and demographic characteristics, often parallel streets several blocks away	MVPA (min/week); Made a walking trip (Y/N); Number of walking trips; Walking > 20 min (Y/N); Walking (min/week, if > 20); Made a cycling trip (Y/N); Number of cycling trips; Cycling > 10 min (Y/N); Cycling (min/week, if > 10)	Objective; accelerometry and GPS	Baseline: Jul. 2010–Nov. 2010 April 2011–Sept. 2011 Trail opened: N.I. Follow-up: Aug. 2012–Nov. 2012 Apr. 2013–Aug. 2013 Exposure: 2–12 months (reported)
Evenson et al. (2005)	Durham, North Carolina, USA	Extension of a 3.2-mile rail-to-trail conversion (10 ft wide and paved for pedestrians, bicyclists and others) by 2.8 miles, along with a 2.0-mile spur	366 adults (≥ 18 y) living within 2 miles of the trail.	Quasi-experimental pre-post design without control group.	N.A.	Leisure activity (min/week); Leisure activity near home (min/week); Total walking (min/week); Total cycling (min/week); MPA (min/week); VPA (min/week); Walking for transportation (min/week); Cycling for transportation (min/week)	Subjective; Telephone survey following the BRFSS	Baseline: Jul. 2000–April 2001 Trail opened: Sep. 2002 Follow-up: Nov. 2002 Exposure: 2 months (calculated)
Fitzhugh et al. (2010)	Knoxville, Tennessee, USA	Construction of an 8-foot-wide and 2.9-mile-long asphalt greenway providing pedestrian-friendly links among residences, businesses, schools and other public spaces.	Children, adolescents and adults in free-living conditions.	Quasi-experimental research design with multiple control neighborhoods.	One intervention neighborhood. Two control neighborhoods matched on socioeconomic dimensions.	2-h count of overall PA; 2-h count of walkers; 2-h count of cyclists	Objective; Direct observation	Baseline: Mar. 2005 Trail opened: Dec. 2005 Follow-up: March 2007 Exposure: 14 months (reported)
Heesch et al. (2016)	Brisbane, Queensland, Australia	Construction of a 2.3 km long segment, as a part of an 17 km long, 3 m wide off-road bikeway.	Adults in free-living conditions.	Natural experiment.	One intervention trail, one existing off-road biking trail and one major arterial road without lane markings for bicycles.	Bicycle counts per month	Objective; Strava mobile phone application	Baseline: August 20th, 2009 Trail opened: June 25 2013 Follow-up September 18th, 2013 Exposure: 3 months (calculated)

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Table 2 (*continued*)

Author, year	Study location	Description BEICs	Study population	Study design	Control sites/exposure groups	Outcome measures	Measurement method	Timing follow-up
Parker et al. (2011)	New Orleans, LA, USA	A 3.1 mile bike lane was located between the outside travel lanes and the parking lane alongside Louisiana Highway 46. Bike lanes were striped on both sides of the road and lanes are 5 ft (1.52 m) wide.	Men, women, adults and children riding a bicycle with traffic, against traffic and on Sidewalks.	Quasi-experiment without control group.	N.A.	Number of cyclists	Objective; Direct observation	Baseline: Nov. 2007 Trail opened: Spring 2008 Follow-up: Nov. 2008 Exposure: 6 months (reported)
Parker et al. (2013)	New Orleans, LA, USA	A 1-mile bikelane which was striped on both sides of the road and 5ft (1.52 m) wide. Bikelanes were located between the travel lane and the parking lane.	Men, women, adults and children riding a bicycle with traffic, against traffic and on sidewalks.	Quasi-experiment.	One intervention street. Two control streets without bike lane one block off the intervention street.	Number of cyclists	Objective; Direct observation	Baseline: September 2009 Trail opened: June 2010 Follow-up: September 2010 Exposure: 3 months (calculated)
Pazin et al. (2016)	Florianopolis, SC, Brazil	New avenue, parking lots, and an on-road walking and cycling route (2.3 km long) along the seashore. A new project is in preparation to add 8.3 km to this walking and cycling route.	745 adults (> 18y) living in six neighborhoods within 1500 m from the new route.	Longitudinal quasi-experiment.	Participants were assigned to one out of three groups based on exposure to the intervention: 0-500 m, 501–1000 m and 1001–1500 m.	Leisure-time PA (min/week); Walking (min/week); Walking + MVPA (min/week)	Subjective: IPAQ	Baseline: Mar. 2009–Jul. 2009 Trail opened: July 2010 Follow-up: Mar. 2012–Dec. 2012 Exposure: 20-29 months (reported)
1) Rissel et al. (2015) 2) Crane et al. (2017)	Sydney, New-South Wales, Australia	A new 2.4 km bi-directional separated bicycle path in inner Sydney.	512 (1) and 418 (2) adults (18-55y) who had ridden a bicycle before and had no current disability preventing them from riding, divided into an intervention (n = 240 (1), n = 189 (2)) and control group (n = 272 (1), n = 229 (2)). Intervention group lived not more than 2.5 km away from the bicycle path.	Longitudinal, quasi-experiment.	1) Participants in the intervention area lived within 2.5 km from the intervention area. Participants in the comparison area lived in neighborhoods with a similar distance from the central business district and with a similar demographic profile. 2) Participants were assigned to one of three groups based on proximity to the intervention: living within 1.0 km, between 1.0-2.99 km and living > 3 km away from intervention area.	Number of cyclists; Weekly frequency of cycling (min/week); Cycling duration (min/week); Travel to work by bicycle	Objective: Fixed electronic bike counts Subjective: 7-day travel diary	Baseline: Sep. 2013–Oct. 2013 Trail opened: N.I. 1) Follow-up I: Sep. 2014–Oct. 2014 Follow-up II: 1 + 2) Sep. 2015–Nov. 2015 Exposure: 1) 4 months (reported) 1 + 2) 16 months (calculated)
West and Shores (2011)	Midsized Southeastern US city	5 miles of greenway were developed and added to an existing greenway along a river in a midsized Southeastern US city.	169 property owners living within .50 miles (n = 95) and within .51 and 1.0 miles (n = 74) of the greenway.	Quasi-experimental design with control group	Participants were assigned to one of two groups based on exposure to the intervention: living within .50 miles and living .51-1.0 miles away from intervention.	Walking (days/week); MPA (days/week); VPA (days/week)	Subjective: Questionnaire	Baseline: Dec. 2007 Trail opened: early 2008 Follow-up: Dec. 2008 Exposure: 11 months (reported)
West and Shores (2015)	Charlotte, North Carolina, USA	1.93 miles of greenway was developed and added to an existing greenway.	203 Property owners living within 1 mile of the greenway (n = 118) or 2-3 miles from the greenway. (n = 85)	Quasi-experimental design with control group.	Participants in intervention group lived within 1 mile from the intervention. Participants of the control group lived within 2.0-3.0 miles from the intervention.	Walking (days/week); MPA (days/week); VPA (days/week)	Subjective: Questionnaire	Baseline: Dec. 2009 Opening: 2010 Follow-up: 2011 Exposure: Little less than 1 year (reported)

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Table 2 (*continued*)

Author, year	Study location	Description BEICs	Study population	Study design	Control sites/exposure groups	Outcome measures	Measurement method	Timing follow-up
BE infrastructural change affecting total infrastructural system.								
1) Goodman et al. (2014) 2) Song et al. (2017) 3) Panter et al. (2017)	Cardiff, Kenilworth and Southampton, UK	Construction of a traffic-free bridge in Cardiff and Kenilworth and the conversion of an informal riverside footpath into a boardwalk in Southampton. Improvement and development of existing and feeder routes.	Randomly selected adults (≥18 y) living within 5km from core projects. 1796 (1) and 1906 (2) residents participated at follow-up I and 1465 (1), 1564 (2) at follow-up II. 1257 (3) participated in both follow-ups.	Quasi-experimental cohort study.	An individual measure of proximity was used to represent exposure to intervention.	Walking and cycling for transportation and recreation (min/week); Overall PA (min/week); MVPA other than walking and cycling (min/week); Walking for transportation (min/week); Cycling for transportation (min/week)	Subjective; IPAQ 7-day recall instrument	Baseline: Apr. 2010 Trail opened: Southampton and Cardiff – Jul. 2010 Kenilworth – Sep. 2011 Follow-ups (1 & 2-year): Ap. 2011 Apr. 2012 Exposure: Southampton and Cardiff: 9 and 21 months Kenilworth: 0 and 7 months
1) Heinen et al. (2015) 2) Heinen et al. (2017) 3) Panter et al. (2016)	Cambridgeshire, UK	Construction of a 25 km off-road guideway for buses, with a parallel path for walking and cycling.	Cohort of 470 (1), 347 (2) and 469 (3) adults (≥ 16 years) working in areas of Cambridge to be served by the busway and living within approximately 30 km of the city center;	Quasi-experimental cohort study.	An individual measure of proximity was used to represent exposure to intervention.	Change in commute mode share; Mode(s) of travel to and from work; Walking and cycling for recreation (min/week); Walking for recreation (min/week); Cycling for recreation (min/week); Total walking and cycling (min/week); Total walking (min/week); Total cycling (min/week); Total recreational physical activity (min/week); Total physical activity (min/week) Active commuting (min/week); Walking on the commute (min/week); Cycling on the commute (min/week)	Subjective; RPAQ 7-day commute travel diary	Baseline: May 2009–Oct. 2009 BEIC opened: Aug. 2011 Follow-up: May 2012–Oct. 2012 Exposure: 9–14 months (reported)

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Table 2 (*continued*)

Author, year	Study location	Description BEICs	Study population	Study design	Control sites/exposure groups	Outcome measures	Measurement method	Timing follow-up
Krizek et al. (2009)	Minneapolis, Minnesota, USA	Installation of on- and off-street bicycle lanes (total of 14 km and 25 km, respectively), short lane striping.	Adults living in Minneapolis/St. Paul. Exact number not provided.	Repeat cross-sectional with comparison group	An area-based measure of proximity was used to represent exposure to intervention.	Proportion of bicycle commuters among all commuters;	Subjective; US Census – The Census Transportation Planning Package	Baseline: 1990 Trails opened: During study period (1990–2000) Follow-up: 2000 Exposure: N.I.
Hirsch et al. (2017)	Minneapolis, Minnesota, USA	Addition of two off-road paved paths (total length of 10.2 miles), transecting the city north-south and east-west, including a dedicated bicycle/pedestrian bridge over a busy freeway.	Employees of 16 years and older, living in one of the 116 selected tracts in the Minneapolis/St. Paul area.	Longitudinal repeated cross-sectional study.	An area-based measure of proximity was used to represent exposure to intervention.	Change in proportion of bicycle commuting	Subjective; Census 2000 and American Community Survey 2008–2012	Baseline: 2000 Trails opened: Components were constructed between 2000 and 2007 Follow-up: 2008-2012 (5-year average) Exposure: N.I.

BRFSS = Behavioral Risk Factor Surveillance System; IPAQ = International Physical Activity Questionnaire; RPAQ = Recent Physical Activity Questionnaire.

Four studies investigated the effect of proximity to the intervention area on the outcomes (Crane et al., 2017; Pazin et al., 2016; West et al., 2011, 2015). One study found that living closer to the intervention led to more overall PA and walking (Pazin et al., 2016) and one study found that living between 1.0 and 2.99 km from the intervention area was associated with a higher increase of cycling compared with individuals living closer (< 1.0 km) or further away (> 3.0 km) (Crane et al., 2017). Two other articles did not report any significant interaction (West et al., 2011, 2015).

3.4.2. Built environment infrastructural changes affecting the total infrastructural system

Eight studies evaluated four unique BEICs affecting the total infrastructural system. The implementation of traffic free bridges and an informal boardwalk, and a busway with parallel walking and/or cycling trail resulted mainly in non-significant and negative effects on overall PA, walking, bicycling, walking and bicycling (Goodman et al., 2014; Heinen et al., 2015, 2017; Panter et al., 2016; Panter et al., 2017; Song et al., 2017). Two studies found positive effects. Hirsch et al. (2017) and Krizek et al. (2009) both found increases in bicycling after the interventions.

For all four BEICs affecting the total infrastructural system, the included studies tested whether proximity to the intervention area was associated with changes in PA outcomes. All studies found non-significant or positive associations between proximity to the intervention area and PA outcomes. Proximity to the intervention was associated with more overall PA and more walking and bicycling at the second follow-up of Goodman et al. (2014), 9–21 months after the implementation of the BEICs, but not at the first follow-up after 0–9 months (Goodman et al., 2014). Also, living closer to the busway and the BEICs in Minnesota resulted in more bicycling and combined walking and bicycling compared to living further away (Heinen et al., 2017; Hirsch et al., 2017; Krizek et al., 2009).

4. Discussion

4.1. Main findings

This study systematically reviewed the available literature on the effect of BEICs on PA and AT. In total, 19 articles were included and assessed. We found that the implementation of single on- and off-road bicycling and/or walking trails resulted in inconsistent effects on PA and walking, but predominantly positive effects on bicycling. More extensive BEICs such as the implementation of a bus lane with parallel walking and bicycling trail and traffic-free bridges resulted also in mixed results, predominantly non-significant effects. However, when taking proximity to the intervention into account, bicycling seems to increase after BEICs. None of the studies measured SB. The majority of the studies was designed or executed before the effects of SB on several health outcomes and cardio-metabolic risk (Ekelund et al., 2016) became more evident and subsequently gained attention in studies. The current state of evidence emphasizes the need to include SB into future studies. Some undesirable effects were detected as well; four BEICs resulted in decreases in overall PA, bicycling and/or walking and bicycling. Overall, our findings partly support the results of previous systematic reviews (Mayne et al., 2015; Smith et al., 2017), but what our review adds is that the effectiveness of BEICs varies greatly across intervention types and types of outcome measure. Not all infrastructural interventions result in positive effects for PA and/or AT. Studies specifically targeting PA and small interventions showed more effects than those addressing more global and drastic infrastructural changes such as the construction of a traffic-free bridges.

When interpreting these results, it is important to consider both the effect of the magnitude of an intervention and the effect of the study quality on the results. The magnitude of the BEICs varied among studies in this review. On- and off-road bicycling and/or walking trails are

Table 3
Results of included studies.

Author(s) (year)	Intervention type		Results					Results based on proximity to intervention				
	On- and off-road bicycling/walking trail	BEICs affecting the total infrastructural system	Overall PA	Walking	Bicycling	Walking and bicycling/ active commuting	SB	Overall PA	Walking	Bicycling	Walking and bicycling/ active commuting	SB
Dill et al. (2014)	•		0	0	0/−							
Evenson et al. (2005)	•		0/−	0	0							
Fitzhugh et al. (2010)	•		+	+	+							
Heesch et al. (2016)	•				+							
Rissel et al. (2015); Crane et al. (2017)	•				+ /0			0		+		
Parker et al. (2011)	•				+							
Parker et al. (2013)	•				+							
Pazin et al. (2016)	•							0/+	+			
West et al. (2011)	•		+	+				0	0			
West et al. (2015)	•		0	0				0				
Goodman et al. (2014); Song et al. (2017); Panter et al. (2017)		•	0/−	−	0	0		0/+	0/+		0/+	
Heinen et al. (2015); Heinen et al. (2017); Panter et al. (2016)		•	0	0	−	0/−		0	0	+	0/+	
Hirsch et al. (2017)		•			+					+		
Krizek et al. (2009)		•			+					+		

relatively small interventions, specifically targeting the promotion of PA and AT. On the other hand, more extensive interventions typically imply major changes to whole (infrastructural) systems (Rutter et al., 2017). This type of BEIC may eventually lead to changes in PA, AT and SB, but also to compensatory adaptive processes and feedback loops that make it harder to assess clear mechanistic pathways and direct effects (Hamid, 2009). Studies evaluating specific behavioral outcomes of extensive interventions may give insights in details at the expense of detecting more general changes in the broader system. Similarly, evaluating specific behavioral outcomes of relatively small interventions, such as bike counting at bike trails, increases the likelihood of finding effects which may reflect a substitution of PA behaviors rather than a change in overall PA.

We also found variation in the total risk of bias in the included studies. As stated, due to the limitations of the assessment tool, the risk of bias assessment was not used to determine the absolute risk of bias, but to compare the study quality among the included studies. The risk of bias in the studies evaluating on- and off-road walking and/or bicycling trails was generally higher than that in the studies assessing more extensive infrastructural interventions, especially in the domains of outcome measurement bias and bias in the selection of reported results. We found that more recent articles tended to find more non-significant results compared to older articles, while the quality of the articles seems to improve over time. Studies with a higher risk of bias were more likely to report significant changes in outcomes than studies with a lower risk of bias.

In line with Craig's (2012) recommendations, recent studies included in this review mainly reported on extensive BEICs and used more refined and complex study designs, i.e. lower risk of bias. Applying these more refined and complex designs seem to decrease the possibility to detect significant changes in PA and AT. The effectiveness of extensive BEICs on PA and AT might therefore be underestimated compared to studies evaluating the implementation of walking and/or bicycling trails and using simpler and straightforward study designs. Moreover, the results of the more simple and straightforward studies are at greater risk of bias and therefore need to be interpret with caution.

One of the elements that were used to make the designs more refined is the assessment of individual-level exposure to the intervention. Humphreys et al. (2016) described three possible methods to assess exposure to the intervention area whereas the most practical and straightforward one is area-based exposure in which existing administrative spatial boundaries are used to create groups. A more refined method is to create exposure groups based on individually computed proximity to the intervention. The most sophisticated way to create groups based on exposure to BEICs is to assess individually calibrated exposure, which determines whether exposure is likely to occur based on pre-existing behavior. Remarkably, all negative outcomes that were found for BEICs affecting the total infrastructural system were turned into non-significant or even positive effects when proximity was taken into account. This emphasized on the need to measure proximity to the intervention area, especially in complex system changes.

Furthermore, the amount of time between the BEICs and the follow-up measurements might affect the results. Two studies assessing on- and –off road bicycling and/or walking trails had follow-up measurements > 12 months after opening of the intervention area and both found solely positive effects on overall PA, walking and bicycling (Crane et al., 2017; Fitzhugh et al., 2010; Pazin et al., 2016). For BEICs affecting the total infrastructural system, two studies had a follow-up > 12 months. Although the outcomes were not consistent, none of the studies with a follow-up time longer than 12 months reported negative results. This confirms previous indications that sufficient time between the BEICs and follow-up measurements are needed (Mayne et al., 2015). Also, multiple follow-up measurements enable to evaluate behavior changes over time.

Another important factor affecting the quality of studies is the

Table 4
Key findings of included studies.

Author, year	On- and –off-road bicycling/ walking trails	BEICs affecting total infrastructural system	Overall PA	Walking	Bicycling	Walking and bicycling/Active commuting	SB
Dill et al. (2014)	•		No changes	No changes	Living in the intervention area was negatively correlated with minutes of cycling and number of cycling trips.	N.A.	N.A.
Evenson et al. (2005)	•		VPA decreased at follow-up for both users and non-users of the trail. MPA decreased for non-users	No changes in overall sample.	No changes in overall sample. Minutes per month bicycling for transportation decreased for those who never used the trail.	N.A.	N.A.
				Participants who used the trail were less likely to increase their walking by > 30 min or 45 min per week	Participants who used the trail were more likely to decrease bicycling time		
Fitzhugh et al. (2010)	•		After intervention, total count of PA was significantly higher in experimental neighborhoods compared to control neighborhoods. In experimental neighborhoods, total PA increased over time. In control neighborhoods, total PA decreased over time.	Number of walkers was significantly higher in experimental neighbourhood at follow-up. Changes in walking significantly differed between experimental and control group.	Number of cyclists was significantly higher in experimental neighbourhood at follow-up. Changes in cycling significantly differed between experimental and control groups	N.A.	N.A
Heesch et al. (2010)	•		N.A.	N.A.	The GPS bicycle counts increased monthly at the intervention trail and did not change on the other routes.	N.A.	N.A.
Rissel et al. (2015); Crane et al. (2017)	•		N.A.	N.A.	Number of cyclists increased with 23% and 97% at two points at the trail, compared to 3% in the whole city at follow-up I. At follow-up II, the number of cyclists increased by 0.9% and 6.4% from baseline, in contrast to a − 2.0% reduction in bike counts across Sidney city council. Weekly frequency of cycling did not change over time at follow-up I. Participants in the intervention group reported a higher frequency of cycling compared with the control group, at follow-up II. Cyclists living between 1.00 and 2.99 km away from the intervention area increased minutes of cycling per week compared with cyclists living further away (> 3 km). MVPA did not significantly change for one of the groups. At follow-up I, travel to work or study by bicycle decreased in all groups. No difference between intervention and control area. At follow-up II, travel to work was not reported.	N.A.	N.A.
Parker et al. (2011)	•		N.A.	N.A.	Number of cyclists per day increased after intervention.	N.A.	N.A.
Parker et al. (2013)	•		N.A.	N.A.	Increase of cyclists on all streets. The number of cyclists increased on intervention streets but decreased on adjacent side streets.	N.A.	N.A.

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Table 4 (*continued*)

Author, year	On- and –off-road bicycling/ walking trails	BEICs affecting total infrastructural system	Overall PA	Walking	Bicycling	Walking and bicycling/Active commuting	SB
Pazin et al. (2016)	•		No change in moderate-to-vigorous leisure time PA in any exposure group.	General increase of walking and a higher weekly volume of walking at follow-up among residents up to 500 m from the new route compared to those living further away.	N.A.	N.A.	N.A.
			Walking + leisure time MVPA increased among individuals living closest to the intervention area, but not for those living further away.	Leisure-time walking increased by 32 min/week among residents living up to 500 m from the new walking and cycling route, while remained stable in groups further away from the intervention area.			
West et al. (2011)	•		On average, number of days participating in MPA and VPA increased (significance not reported).	Walking increased after intervention (significance not reported).	N.A.	N.A.	N.A.
			No significant interactions between intervention and proximity for MPA and VPA.	No significant interaction between intervention and proximity.			
West et al. (2015)	•		MPA and VPA did not change over time.	Days of walking did not change over time.	N.A.	N.A.	N.A.
			No significant interaction between residential proximity to the intervention and greenway development for MPA or VPA.				
Goodman et al. (2014); Song et al. (2017); Panter et al. (2017)		•	At follow-up I, mean levels of MVPA (other than walking/cycling) declined.	Median total time spent walking decreased between baseline and follow-up.	N.A.	At follow-up I, Mean levels of walking and cycling for transport and recreation did not change. No proximity effect for total walking and cycling was detected.	N.A.
			No proximity effect for PA outcomes.	Participants living closer to the intervention were more likely to take up walking for transport. Proximity to the intervention was not associated with total walking or walking for recreation.		At follow-up II, mean levels of walking and cycling for transport and recreation did not change. Individuals living closer to the intervention area reported increases in walking and cycling, relative to those living farther away.	
			At follow-up II, mean levels of MVPA (other than walking/cycling) declined over time. Proximity to the intervention was associated with increased total PA, but not with MVPA other than walking and cycling.				
						Proximity to the intervention was not associated with a modal shift from motorized to active transportation. Use was associated with a modal shift from motorized to active transport.	

(*continued on next page*)

Table 4 (*continued*)

Author, year	On- and –off-road bicycling/ walking trails	BEICs affecting total infrastructural system	Overall PA	Walking	Bicycling	Walking and bicycling/Active commuting	SB
Heinen et al. (2015); Heinen et al. (2017); Panter et al. (2016)		•	Total physical activity and total recreational PA did not change over time.	Minutes of cycling per week declined over time.	N.A.	In maximally adjusted models, proximity predicted a large increase in active travel mode share and reduced the likelihood of a small decrease in active travel mode.	N.A.
			No exposure effect on recreational or overall PA	Exposure to the busway was associated with a significantly greater likelihood of an increase in weekly cycle commuting.		No significant association between level of exposure to the intervention and specific modal shifts or the belonging to a group that showed a full or partial modal shift.	
				Walking on the commute and for recreation did not significantly change over time. No exposure effect on walking.		Time spent in active commuting decreased over time. Exposure to the busway was not associated with combined walking and cycling.	
Hirsch et al. (2017)		•	N.A	N.A.	Overall percentage of commuting by bicycle increased after implementation of trails. Increases in bicycle commuting restricted to tracts close to the off-road trail system.	N.A.	N.A.
Krizek et al. (2009)		•	N.A.	N.A.	Bicycle mode share increased in the overall sample, but the areas with new cycling facilities showed a larger increase compared to the areas without new cycling facilities.	N.A.	N.A.

method and protocol used to measure PA and AT. Studies included in this systematic review used questionnaires, systematic observations, electronic bike counts or a combination of accelerometry and GPS to assess PA and AT. Remarkably, all studies reporting counts for bicycling, walking and/or PA found increased overall PA, walking and/or bicycling levels after BEICs. However, three studies did not include a control area in their observations (Crane et al., 2017; Parker et al., 2011; Rissel et al., 2015) and the other two found decreased PA levels in adjacent streets (Fitzhugh et al., 2010; Parker et al., 2013). This suggests that the interventions led to changes in cycling routes rather than a change in the AT behavior of residents. Individual-level, objective full-day PA measurements would be necessary to test this hypothesis.

Although the use of accelerometry has resulted in better validity and reliability when measuring PA compared to questionnaires, only one study used accelerometers to assess PA (Dill et al., 2014). This study found no effect of living in the intervention area on PA, but they only assessed overall daily MVPA. Other researchers have reported that inconsistencies in their findings may be due to measuring PA in only one domain (e.g. overall PA or total MVPA) instead of measuring context-specific PA patterns (Klinker et al., 2015). Context-specific PA patterns can be defined as daily PA assessed in total and in different domains throughout the day, with context referring to the domain in which behavior occurs. Using context-specific objective measures enables researchers to assess how and where PA or SB behavior takes place and how PA in one domain relates to PA in other domains. It can identify changes in PA or SB behaviors during the day that do not affect total daily PA. In other words, measuring daily PA involves an increased risk of “missing” changes in PA at specific moments in time that are potentially compensated at other moments during the day, as the Activitystat hypothesis suggests (Rowland, 1998). By measuring context-specific PA and SB patterns, it is possible to identify these potentially important changes in behavior while retaining the possibility to assess potential compensation. Current objective PA monitors are limited in terms of their capacity to identify context-specific behaviors. GPS loggers can add valuable information about places and contexts to PA measurements, and the combination of accelerometry and GPS will then help to overcome the limitation of current activity monitors in identifying specific PA and SB behaviors (Atkin et al., 2016; Koohsari et al., 2015).

The context in which infrastructural interventions are delivered and received is also crucial for the ability to explain how the impact of an intervention differs in different settings. In this case, “context” includes any factors which are external to the intervention, but which may obstruct or enhance its effects (Moore et al., 2014). To determine the relevance and translatability of results, researchers should carefully and systematically describe the context in which the intervention was developed, applied and evaluated (Campbell et al., 2007). In the current review, the variety of contexts in which the infrastructural interventions were delivered and the insufficient ways in which they are described might explain the variance in results (Atkin et al., 2016). Therefore, future studies should specifically report the context in which BEICs take place. Further, eleven out of fifteen unique interventions took place in the USA and Australia and all three unique interventions in Europe were executed in the UK. Previous research has shown that AT is much more common in Europe than in North America, Australia and the UK (Bassett et al., 2008; Pucher and Buehler, 2008). European countries such as Germany, Denmark and The Netherlands are more compact, leading to smaller trip distances, which might be important in the choice between active and passive transportation (Pucher and Buehler, 2008). The higher prevalence of AT makes it more difficult to detect significant increases in AT as result of BEICs. Therefore, when designing future experiments in these European countries, researchers should consider this complexity and design high quality studies to be able to detect changes in PA, AT and SB behavior.

4.2. Strengths and limitations

In this study, we used a systematic strategy to identify eligible articles. The selection process was done by two reviewers separately. Also, this review has focused on the effects of BEICs on PA, AT and SB among adults, rather than including a broad range of interventions in the BE and or social initiatives and a variety of participants, e.g. children and elderly people. A first limitation is that the specificity of the research question led to only a small number of eligible articles. In addition, articles published in transport- journals might not be added to the health-related databases which were searched for this review. This could potentially lead to missing articles. We tried to limit this issue by checking the references of included studies and other relevant systematic reviews.

Further, even though the search focused on infrastructural interventions only, we found a lot of variation in the magnitude, content and context of interventions that may have had an important impact on our results. This underlines the need for a better description of the context in which an intervention was effective or not. Also, outcome measures differed tremendously among the included studies, which made it impossible to compare them directly and to calculate effect sizes.

Finally, the specificity of this review led to the exclusion of public transport interventions such as the implementation of light rails or shared bike systems. There is evidence that public transport interventions can lead to an increase of PA and AT levels (Miller et al., 2015; Rissel et al., 2012). However, motives and barriers to engage in public transport differ from those that are associated with infrastructural changes in that they do not only include physical barriers and perceptual barriers which are found in AT and PA (Manaugh et al., 2017), but also service barriers and information barriers (Peck, 2010).

4.3. Recommendations

This systematic review has discussed several important factors that influence the quality of quasi-experiments and natural experiments. Lower quality studies may show effects that do not represent actual changes in PA, AT and SB. Although it is challenging and expensive, there is need for high-quality experiments in the future, using objective, context-specific PA measurements. This is necessary to detect changes in PA, AT and SB patterns other than changes in overall PA, AT and SB levels. Also, future studies should consider to not only use multiple groups based on proximity to the intervention, but also to determine individual-level proximity and actual exposure to the intervention (or intervention area), using objective measurements. In addition, the context in which interventions are implemented should be described more in detail to make it possible for researchers and policy makers to determine the relevance and transferability of results to other places and contexts.

4.4. Conclusion

This systematic review found that BEICs can lead to changes in overall PA and AT, with the most promising results for bicycling. However, the current state of evidence is inconclusive. Improved understanding of the potential of BEICs to increase PA levels and decrease SB at population level asks for more high-quality, in-depth research, while taking into account the broader system in which the intervention takes place. Even though the quality of quasi-experiments and natural experiments seems to improve over time, the following methodological improvements should be considered when designing a natural experiment: the use of objective context-specific PA, AT and SB measurements, provision of detailed descriptions of the context in which interventions take place, inclusion of multiple groups based on proximity to the intervention, and assessment of individual-level exposure and proximity to the intervention.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.healthplace.2018.08.002.

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