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Changes in bicycling frequency in children and adults after bicycle skills training: A scoping review

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A B S T R A C T

Background: Encouraging more trips by bicycle is often an objective of bicycle skills training. Bicycle skills training programs have been implemented in several countries, cities, and schools, but few evaluations measure changes in bicycling. We conducted a scoping review to identify and describe evidence of changes in bicycling frequency associated with bicycle skills training. We also describe and compare the theoretical basis, context, and training content of bicycle skills trainings that might be associated with changes in bicycling.
Methods: We searched six electronic databases, grey literature websites, Google Scholar, and citations in relevant articles for pre- and post-test studies of bicycle skill training interventions which measured bicycling frequency in children or adults. We assessed the theory, context, and content of the bicycle skills training interventions using pre-defined concepts and a behaviour change technique taxonomy.
Results: We found 12 studies. Six studies assessed programs for adult populations, of which five reported increases in overall bicycling and three reported increases in bicycling to work. Six studies assessed programs for children, of which five reported increases in overall bicycling and three reported increases in bicycling to school. Information about the statistical significance of these results was sometimes missing. Studies described intervention content adequately, but poorly reported details about intervention theory and context. No associations were found between intervention content and changes in bicycling frequency.
Conclusions: Bicycle skills training increases participants' bicycling, but evidence is heterogeneous among a small number of studies. Sparse reporting limited our ability to detect associations between changes in bicycling frequency and the training theory, context, or content. Future studies should strive to report details on theory, context, and content to help assess effectiveness and generalizability.

1. Introduction

Bicycling offers important health, transport, and environmental benefits (Götschi et al., 2016; Lindsay et al., 2011; Zahabi et al., 2016), and cities around the world are looking for potential ways to increase levels of active travel by bicycle. Together with supportive infrastructure and changing social environments, experts suggest that bicycle skills training has potential for increasing ridership (Pucher et al., 2010). Developing and implementing effective interventions to increase bicycling relies on understanding its correlates and determinants. Many studies have found that safety concerns from riding in traffic pose a barrier in people's decisions about whether or not to use a bicycle (Lawson et al., 2013; Sanders, 2015; Winters et al., 2012, 2011), as do related constructs such as confidence or comfort (Emond and Handy, 2012; Willis et al., 2015; Xing et al., 2010). Bicycle skills training has been proposed as a strategy to increase bicycling by giving participants greater confidence to ride (Goodman et al., 2016; Rissel and Watkins, 2014).

Bicycle skills training interventions are diverse in aim, delivery mode, and objectives. For example, in terms of aims and objectives, bicycle skills training has been described as helping participants to "overcome skill, knowledge, and confidence related

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barriers to cycling" (Rissel and Watkins, 2014, p. 135), teaching "road awareness and how to cycle on the road" (Mandic et al., 2016, p. 219), aiming to "increase participation in cycling, particularly cycling for transport trips" (Hawley and Mackie, 2015, p. 6), or as encouraging children to "cycle more safely, more often, by giving them the skills and confidence to cycle" (Goodman et al., 2015, p. 513; Johnson et al., 2016, p. 52). Bicycle skills training can serve diverse audiences with respect to skills and experience, ranging from children and adults learning to ride for the first time, to those with some basic or even advanced bicycle handling skills wishing to gain further competence in using bicycles in urban environments. However, there are few published studies of bicycle skills training, and little evidence is available to demonstrate whether such training does encourage more bicycling. Most studies of children's bicycle training have measured changes in knowledge, skills, attitudes, helmet use, safety awareness, or injury rates (Hooshmand et al., 2014; Lachapelle et al., 2013; Richmond et al., 2013). There has not been a synthesis of evidence on the impact of bicycle skills training on increases in bicycling frequency (i.e., changes to the amount of bicycling), despite this being a primary rationale for training.

Moreover, little is known about which programs may work most effectively, under what conditions, and for which populations. An important aspect of designing and reporting interventions and evaluations is drawing explicit links between theory, context, and content. Researchers have called for further development into intervention reporting, including better descriptions of theoretical approaches used to guide intervention designs and measured outcomes (Bartholomew and Mullen, 2011; Davidoff et al., 2015; Moore and Evans, 2017), consideration of context (Hawe, 2015; Shoveller et al., 2016), and more detailed intervention description (Albrecht et al., 2013; Borek et al., 2015; Hoffmann et al., 2014; Michie et al., 2009). Researchers are encouraged not only to establish that an intervention works, but also to identify and explain the specific ways in which it works (Moore et al., 2015). Theory becomes especially important for interventions that are delivered in different contexts or that are tailored or modified to meet the needs of participants (Walshe, 2007), such as bicycle skills training.

Research on population-level bicycling rates across countries and cities indicates that certain contextual elements underpin higher bicycle mode share. We understand *context* as an essential foundation that "interacts, influences, modifies, facilitates or constrains the intervention and its effectiveness" (Coles et al., 2017, p. 2). Higher mode shares are found in countries and cities where there are government policies and programs to promote bicycling and extensive infrastructure and land-use policies to support bicycling (Lanzendorf and Busch-Geertsema, 2014; Pucher et al., 2010; Pucher and Buehler, 2008; Rietveld and Daniel, 2004). Socio-cultural aspects are also important, such as "bicycle culture" or attitudes and meanings toward using bicycles (Aldred and Jungnickel, 2014; Goetzke and Rave, 2010; Klinger et al., 2013). Considering these contextual differences, we would expect the effects of bicycle skills training to differ by place and population.

Scoping reviews can identify current evidence and gaps to inform concepts, frameworks, and practice (Arksey and O'Malley, 2005; Levac et al., 2010; Peterson et al., 2017; Pham et al., 2014; The Joanna Briggs Institute, 2015; Tricco et al., 2016). Given the need for data on bicycling uptake and the limited body of knowledge, we conducted a scoping review to explore existing peer-reviewed and grey literature. Our aim is to identify and describe evidence on changes in bicycling frequency associated with bicycle skills training interventions. Within the identified studies, we also compared the theoretical basis, context, and training content of bicycle skills training interventions that might be associated with increased bicycling frequency. In doing this, we respond to recommendations that reviews should explore intervention content, examine the role of theory (Bird et al., 2013), and go beyond asking 'does it work' to 'does it work in this context?' (Bates and Ellaway, 2016).

2. Methods

Our scoping review followed a pre-defined 5-stage process: (1) identifying research question and (2) relevant studies; (3) selecting studies; (4) charting data; (5) reporting results (Arksey and O'Malley, 2005; Levac et al., 2010; The Joanna Briggs Institute, 2015). We describe these stages below. The scoping review protocol may be obtained from the study authors.

2.1. Scoping review question

To construct the research question, we used the Population, Concept, and Context framing (The Joanna Briggs Institute, 2015). Our *population* is participants in a bicycle skills training. Our *concept*, bicycle skills training, is face-to-face training with a "hands-on" component where participants ride a bicycle. The *context* of interventions is not limited to specific geographic locations, settings or participant demographics. Our search was limited to period 1980–2017. The outcome of interest to the scoping review is any change in bicycling frequency before and after intervention participation.

2.2. Identifying relevant studies

A university librarian assisted with developing the search strategy. We used multiple search strategies: (1) literature indexed in academic databases; (2) grey literature indexed in web sources (defined as grey literature as reports, evaluations, and theses not appearing in scholarly journals); and (3) hand searching. We restricted our search to publication dates 1980–2017 and English language. In June 2017, we searched six academic databases (CINAHL, Ovid MEDLINE, PsycINFO, SPORTDiscus, Transport Research International Documentation (TRID), and Web of Science) using the following terms: (("bicycl*" OR "bike" OR "biking" OR "cycl*") AND ("intervention" OR "training" OR "course" OR "workshop" OR "education" OR "skill*") AND ("transport*" OR "commut*" OR "street" OR "urban")) to focus on utilitarian bicycling. Additionally, three grey literature databases (Canadian Electronic Library, Grey Literature (greylit.org), ProQuest Dissertations and Theses) were searched, as well as Google Scholar. The search strategy was

documented by title of the database searched, date of the search, the complete search string that was used, and the number of articles found. Hand searching strategies included checking references from relevant articles.

2.3. Study selection with predefined inclusion/exclusion criteria

Our inclusion criteria specified three criteria: (1) pre- post-test study design; (2) at least one measure of bicycling frequency; (3) and an intervention with a hands-on training component. Studies were excluded if the interventions targeted injury treatment, weight loss, sport racing, oxygen intake capacity or other fitness performances. Evaluation reports not publicly available were also excluded. Titles and abstracts of publications obtained by the search strategy were independently screened by two reviewers (SS and DD). A third reviewer (MW) adjudicated disagreements.

2.4. Charting data

The data were extracted and charted independently by two reviewers (SS, DD) in Microsoft Excel. Disagreements were resolved by discussion and consultation with a third author (MW). Six types of information were collected: (1) study characteristics; (2) participant description; (3) assessment of the extent to which interventions were based on theory; (4) description of broader intervention context; and (5) intervention description, including (6) behaviour change techniques.

Intervention descriptions were analyzed to identify behaviour change techniques (Michie et al., 2013) included in the training. We completed online training to learn appropriate coding. When intervention descriptions in articles contained insufficient detail to code for behaviour change techniques, we obtained intervention training manuals or contacted authors of studies.

2.4.1. Reporting intervention theory, context, and content

2.4.1.1. Theory. In this paper, we use the term *theory* to mean a systematic way of understanding events or situations, informed by a set of concepts that explain or predict these events/situations by specifying relationships between variables (Glanz and Bishop, 2010). In short, theory clearly explains how and why specific relationships between variables lead to specific outcomes (Nilsen, 2015). These do not need to be formal "off-the-shelf" theories (Moore and Evans, 2017, p. 133); we use the term theory to also mean other approaches where cause-and-effect associations are explicit and clearly mapped to the intervention design (Breuer et al., 2016; Jones and Ogilvie, 2012; Kok et al., 2016; Michie et al., 2016). Thus, the term theory here means both theories of behaviour change as well as the conceptual frameworks that guide the design and evaluation of interventions. We used one item from Michie and Prestwich's (2010) theory coding scheme, a standardized tool with good reliability, to identify and describe the theoretical basis for bicycle skills training. This was "is theory mentioned", with three considerations: (1) if an explicit *theory is mentioned* anywhere in the manuscript, even if the intervention is not based on it; (2) if the study mentions the *predictors of the behaviour* in the introduction or methods sections; and (3) if the *intervention is based* on a theory or theories.

2.4.1.2. Context. To conceptualize and describe broader intervention context, we used a framework by Pfadenhauer et al. (2017) developed to provide guidance for reporting context in reviews and primary studies. In this framework, context comprises seven domains at scales beyond that of the individual: geographical, epidemiological, socio-cultural, socio-economic, ethical, legal, and political. We chose domains based on what the literature has suggested to be important determinants of bicycling: policies (political or legal domain), infrastructure (geographical), and the social milieu (socio-cultural). We assessed if articles had reported contextual information across three areas: (1) political or policies to promote bicycling; (2) built environment characteristics (such as bicycling infrastructure) of geographical location; and (3) bicycling prevalence in the general or target population as a broad proxy for social norms toward bicycling.

2.4.1.3. Content. We report intervention description (setting, provider, format, duration) and use a taxonomy of 93 behaviour change techniques (Michie et al., 2013) to further describe the components of the bicycle skills training interventions. Behaviour change techniques have been used in reviews to link intervention content to theory, and to facilitate intervention comparison and evaluate technique efficacy (Michie et al., 2016).

2.5. Collating, summarizing, and reporting results

We present data summaries in tables accompanied by narrative interpretations. Interventions delivered to adults and children (up to 16 years) are considered separately. As this review did not include human subjects, no institutional review board approval was required.

3. Results

Overall, 1978 articles were identified through database, citation, and hand searching. In total 292 duplicates were removed (Fig. 1). Twelve studies met inclusion criteria: six in adult populations and six in children. Six of these studies are peer-reviewed articles (Ducheyne et al., 2014; Johnson and Margolis, 2013; Rissel and Watkins, 2014; Telfer et al., 2006; van Lierop et al., 2016; Zander et al., 2013), three are reports from the grey literature (two from Transport for London on the same intervention but data could not be pooled; Hatfield et al., 2017), and three are theses (Groesz, 2007; Jones, 2017; Montenegro, 2015).

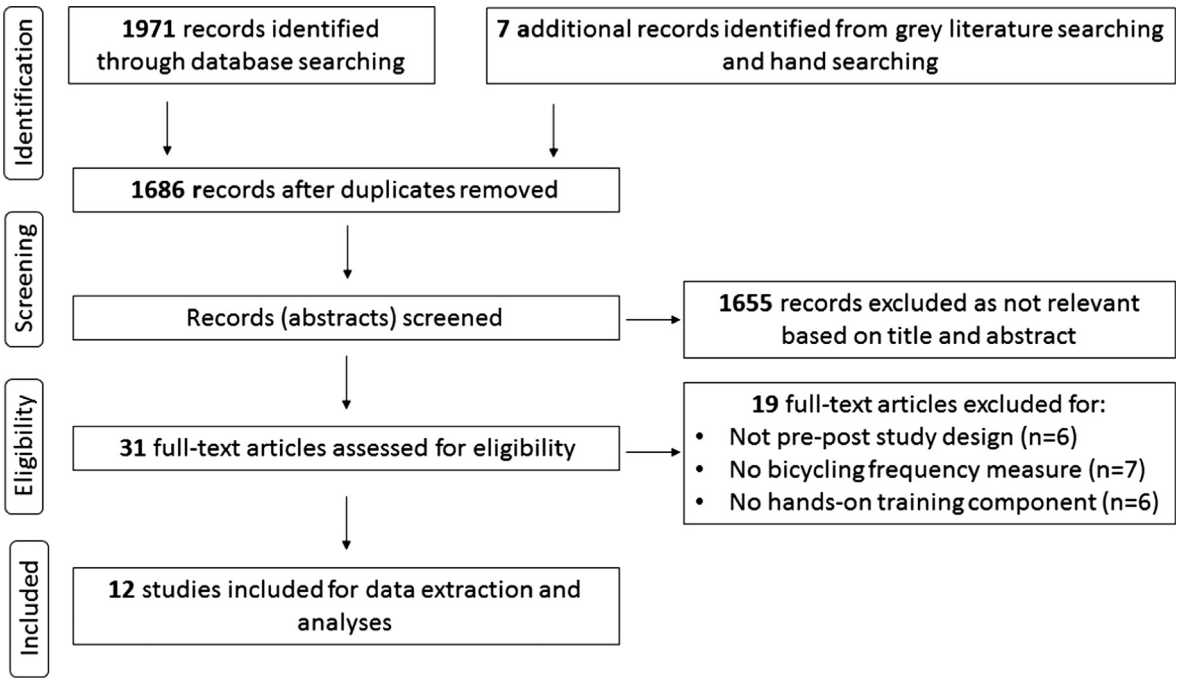

Fig. 1. Selection of studies into the review.

3.1. Characteristics of studies

Table 1 provides a detailed description of the characteristics of included studies. All six studies in adult populations were from Australia or the UK, while the six studies focusing on children were more geographically diverse (Belgium, Ireland, Australia, Canada, and the USA). One included a randomized control group (Ducheyne et al., 2014), and three included a comparison (non-randomly assigned control) group (Groesz, 2007; Hatfield et al., 2015; Jones, 2017). Response rates were not always reported, but all studies reported follow up rates. Five had follow up rates of 90% or higher (Groesz, 2007; Hatfield et al., 2015; Jones, 2017; Montenegro, 2015; Telfer et al., 2006), and four studies 60% or less (Johnson and Margolis, 2013; Rissel and Watkins, 2014; Transport for London, 2017, 2016).

All studies had multiple time points, but follow-up time periods varied. Three studies assessed outcome measures only at baseline and at the end of the intervention period (Montenegro, 2015; van Lierop et al., 2016; Zander et al., 2013), while the other nine studies assessed outcomes between 2 and 12 months post-intervention. Five of the nine studies included multiple post measurements (Hatfield et al., 2015; Jones, 2017; Rissel and Watkins, 2014; Transport for London, 2017, 2016). Of these, three found that bicycling increases were the greatest shortly after the intervention (Rissel and Watkins, 2014; Hatfield et al., 2015; Jones, 2017).

There were a variety of measures used to assess bicycling, all based on self-reported questionnaires or interview data. Most studies asked about bicycling within a specified recall period, for example, number of time bicycled in the previous week, while others asked about bicycling more generally. In terms of bicycling purpose, some papers only measured overall bicycling (n = 2) (Rissel and Watkins, 2014; Zander et al., 2013), others only measured bicycling specific to commuting (n = 2) (Ducheyne et al., 2014; Jones, 2017), and some included both as separate outcomes (n = 8) (Groesz, 2007; Hatfield et al., 2015; Johnson and Margolis, 2013; Montenegro, 2015; Telfer et al., 2006; Transport for London, 2017, 2016; van Lierop et al., 2016).

Table 2 outlines characteristics of study participants. Studies always described participants by gender and often by age, but rarely other defining characteristics of the group such as ethnicity and socio-economic status. Among adult programs, participants were predominantly women, although no program was specifically women-oriented. Courses aimed at children were delivered in schools, with reported populations between 8 and 14 years of age.

3.2. Changes in bicycling frequency

There was variability in findings on changes in bicycle frequency after the bicycle skills training. Most studies reported some increase in bicycling, although the effect size of the intervention was not always reported (Table 1). Five of the six adult intervention studies reported an increase in overall bicycling following the bicycle skills training (all but Telfer et al., 2006), and three found increases in bicycling to work (Johnson and Margolis, 2013; Transport for London, 2017, 2016). Two of the six studies in children found increases in overall bicycling (Hatfield et al., 2015; Montenegro, 2015), three studies (Hatfield et al., 2015; Jones, 2017; Montenegro, 2015) found increases in bicycling to school, and one found increases in recreational bicycling (Groesz, 2007). No significant change in bicycling was found in one of the adult studies (Telfer et al., 2006) or in one of the children studies (Ducheyne

Table 1
Characteristics of bicycle skills training studies included in the review (n = 12).

Author, Year, Country	Follow-Up(s) After Training	Study design, group (n)	Bicycling Frequency Measurement Tool	Bicycling Frequency Measurement(s)	Bicycling Frequency Findings Changes relative to baseline	Direction of change[a]	Secondary Findings
Adult Studies							
Johnson and Margolis (2013), UK	3 months	One-group pretest–posttest design pre (471)/ post (130)	Self-reported online survey	(1) # days/previous week bicycling > 30 min; (2) # days/previous week bicycled to work	(1) mean increase +0.81 days/wk bicycling > 30 min* (2) mean increase +0.67 days/wk bicycling to work*	(1) +* (2) +*	Increase in confidence
Rissel and Watkins (2014), AU	0, 3, 12 months[b]	One-group pretest–posttest design using repeated posttest measures pre (4145)/post 0m[b,c] (2250), post 3m[c,d] (423), post 12m[c,d] (125)	Self-reported paper survey & telephone interview	(1) bicycle in previous week (y/n) (2) bicycle in previous month (y/n)	(1) 16% increase in weekly bicycling at 3m[e]; 12% increase at 12m[e] (2) 30% increase in monthly bicycling at 3m[e]; 14% increase at 12m[e]	(1) +[e] (2) +[e]	Increase in confidence; decrease in weight at 12 m*
Telfer et al. (2006), AU	2 months	One-group pretest–posttest design pre (113)/ post (105)	Self-reported survey & telephone interview	(1) # days/previous week bicycling; (2) # mins/previous week bicycling; (3) # days/previous week bicycling to work	(1) no change in days/wk bicycling (2) mean increase of 10.4 min/wk bicycling 3) no change in days/wk bicycling to work	(1) 0 (2) + (3) 0	Increases in skills, confidence, other Moderate to Vigorous Physical Activity (MVPA)*
Transport for London (TfL) report (2016), UK	3, 12 months	One-group pretest–posttest design using repeated posttest measures pre (800)/ post 3 m[c] (258), post 12 m[c] (101)	Self-reported online survey	# days bicycling[f] for (1) commuting, (2) errands, (3) leisure	Increases in bicycling at 3m[e] follow up for 1) commuting (+0.77 days/wk); 2) errands (+0.89 days/wk); 3) leisure (+0.82 days/wk)	(1) +[e] (2) +[e] (3) +[e]	Increases in access to bikes, safety, confidence[e]
TfL Report (2017), UK	3, 12 months	One-group pretest–posttest design using repeated posttest measures pre (724)/ post 3 m[c] (220), post 12 m[c] (32)	Self-reported online survey	# days bicycling[f] for (1) commuting, (2) errands, (3) leisure	Increases in bicycling at 3m[e] follow up for 1) commuting (+0.73 days/wk); (2) errands (+0.47 days/wk); (3) leisure (+0.66 days/wk)	(1) +[e] (2) +[e] (3) +[e]	Increases in access to bikes, safety, confidence[e]
Zander et al. (2013), AU	0 months[b]	One-group pretest–posttest design pre (17)/ post (11)	Semi-structured interviews	(1) Meet 2 hr/wk bicycling target (y/n)	1) 9 of the 11 participants (82%) met the 2 hr/week bicycling target[e]	(1) +[e]	Increases in mental health, physical fitness, confidence[e]
Child Studies							
Ducheyne et al. (2014), BE	0, 5 months[b]	Randomized Control Trial Three groups: (1) intervention pre (44)/ post	Self-reported paper survey (parents)	(1) # minutes child biked to school in the previous week	Intervention group Mean increase of 7.1 mins/wk at 0 m; mean decrease of 4.1 mins/wk at 5 m	(1) 0/0	Increases in skills*; no change in parent attitudes

(*continued on next page*)

Table 1 (*continued*)

Author, Year, Country	Follow-Up(s) After Training	Study design, group (n)	Bicycling Frequency Measurement Tool	Bicycling Frequency Measurement(s)	Bicycling Frequency Findings Changes relative to baseline	Direction of change[a]	Secondary Findings
		(25); (2) intervention + pre (47)/ post (34); 3) waitlist[g] pre (44)/ post (35)			Intervention + group Mean decrease of 4.4 mins/wk at 0 m; mean decrease of 4.8 mins/wk at 5 m Waitlist group Mean decrease of 5.3 mins/wk at 0 m; mean increase of 3.5 mins/wk at 5 m		
Groesz (2007), US	5 months[c]	Quasi-experimental Two groups: (1) intervention pre (74)/ post (67); (2) waitlist[h] pre (44)/ post (43)	Self-reported paper survey; daily tally (children)[j]	(1) # days biked to school over 10 days[j]; (2) # days biked to school in previous 5 days; (3) hrs/wk recreational bicycling[f]	Intervention group (1) mean increase of 0.06 days/10 days bicycling to school (2) mean decrease of 0.07 days/5 days bicycling to school (3) mean increase of 0.12 hrs/wk recreational bicycling* Waitlist group (1) mean decrease of 0.16 days/10 days bicycling to school (2) mean increase of 0.09 days/5 days bicycling to school; 3) mean decrease of 0.42 hrs/wk recreational bicycling	(1) + (2) − (3) +*	Increases in knowledge, motivation, self-efficacy*
Hatfield et al. (2015), AU	0, 3 months[b]	Quasi-experimental Two groups: (1) intervention pre (112)/ post 0m[b,c] (110), post 3m[c] (108); (2) waitlist[h] pre (30)/ post 0 m[b,c] (35), post 3 m[c] (28)	Self-reported online survey (children)	1) bicycle in previous 2 weeks (y/n); 2) bicycle to school previous 2 weeks (y/n); 3) bicycle using bike lanes previous 2 weeks (y/n); 4) bicycle on road without bike lanes previous 2 weeks (y/n); 5) # days bicycling/ previous 2 weeks on paths or roads	Intervention group (1) 5% increase in bicycling at 0 m*; 2% increase at 3 m (2) 5% increase in bicycling to school at 0 m; 6% increase at 3 m* (3) 3% increase in bicycling using bike lanes at 0 m; 7% increase at 3 m* 4) 4% increase in bicycling on road at 0 m; 8% increase at 3 m* 5) mean increase of 0.38 days/2 weeks bicycling on path or road at 0 m; mean decrease of 0.14 days/2 weeks at 3 m Waitlist group Issues with waitlist group data and not reported	(1) +/+* (2) +/+* (3) +/+* (4) +/+* (5) +/−	Increases in confidence, knowledge*
Jones (2017), IE	0, 1, 6, 12 months[b,c]	Quasi-experimental Two groups:	Self-reported survey paper (children)	(1) ever bicycled to school (y/n);	Intervention (1) 9% increase in ever bicycling to	(1) +/+*/+* (2) +*/+*/+*	Increases in skills, confidence, attitudes*

(*continued on next page*)

Table 1 (*continued*)

Author, Year, Country	Follow-Up(s) After Training	Study design, group (n)	Bicycling Frequency Measurement Tool	Bicycling Frequency Measurement(s)	Bicycling Frequency Findings Changes relative to baseline	Direction of change[a]	Secondary Findings
		1) intervention pre (328)/post 0m[b,c,k], post 1m[c,k], post 6m[c,k], post 12m[c,k]; 2) waitlist[h] pre (303)/ post 0m[b,c,k], post 1m[c,k], post 6m[c,k], post 12m[c,k]		(2) bicycled to school in previous week (y/n)	school at 0 m; 19% increase at 1 m[*]; 21% increase at 6 m[*] (2) 20.5% increase in weekly bicycling to school at 0 m[*]; 8.5% increase at 1 m[*]; 13.5% increase at 6 m[*] Waitlist group (1) 4% increase in ever bicycling to school at 0 m; 7% increase at 1 m; 10% increase at 6 m (2) 0.9% increase in weekly bicycling to school at 0 m; 3.9% increase at 1 m; 4.1% increase at 6 m		
Montenegro (2015), US	0 months[b]	One-group pretest-posttest design pre (1575)/ post (1451)	Self-reported paper survey (children)	(1) bicycle to school sometimes (y/n); (2) ride bike once/week or more (y/n)	(1) 5% increase in bicycling to school[e,f]; (2) 7% increase in weekly riding[e,f]	(1) +[e] (2) +[e]	Increases in skills, confidence[e]
van Lierop et al. (2016), CA	3 months	One-group pretest-posttest design pre (80)/ post (51)	Self-reported online survey (children and parents)	(1) bicycle to school ("a lot like me")[j]; (2) bicycle on weekend ("a lot like me")[j]; (3) bicycle to school when weather allows (parents only, y/n); (4) # days/wk ride bicycles in spring/ summer [f] (children only)	(1) 6% increase reported by children; 16% increase reported by parents (2) 18% increase reported by children[*]; 20% increase reported by parents (3) 24% increase bicycling to school reported by parents[*] (4) decrease in proportion of children choosing "3–5 days/week"[e]	(1) +/+ (2) +[*]/+ (3) +[*] (4) −[e]	Increases in positive attitudes, safety, skills[*]

* Results are statistically significant.
[a] + = increase; − = decrease; 0 = no change or null results; follow up measures separated by /.
[b] 0 months = follow-up immediately after program delivery.
[c] Length of follow-up after program delivery.
[d] Follow-up at 3 and 12 months was a 10% random sample of original survey.
[e] No statistical testing was reported.
[f] No recall period specified in questionnaire item.
[g] Randomly assigned control group waitlisted to eventually receive the intervention.
[h] Non-randomly assigned comparison group waitlisted to eventually receive the intervention.
[i] Respondents asked to respond to question with a 3-point Likert scale; only changes in proportion of children/parents choosing top of Likert scale ("a lot like me") reported.
[j] Children reported travel mode to school via daily tally sheet.
[k] Follow up retention not reported separately for intervention/comparison group, but only for overall study participants: at post 0 m (575); post 1 m (571); post 6 m (571); post 12 m (567).

Table 2
Baseline characteristics of participants in bicycle skills training studies.

Author, Year	Study population size # people receiving intervention (n)[a]	Baseline Sample (n)	Ethnicity (% self-identifying as Black, Asian, Latino/a, or Indigenous)	Gender (% female)	Age[b]	Other	Reported bicycle experience
Adult Studies							
Johnson and Margolis (2013)	471	471	Not reported	82	adults	46% own bicycle	Not reported
Rissel and Watkins (2014)	6700	4145	Not reported	70	17% 18–29, 28% 30–44, 33% 45–59, 23% 60 +	38% do not have bicycle; 61% registered in Austcycle level 1 (i.e., beginner) 49% Body Mass Index (BMI) > 25	9% never bicycled; 24% did not bicycle for one year or more; 12% did not bicycle in past year[c]
Telfer et al. (2006)	113	105	Not reported	75	87% 25–54	36% live < 5 km from work; 77% rated fitness 'fair' or 'good'	Not reported
TfL Report (2016)	8650	800	43	76	37% 16–34, 45% 35–54, 17% > 55	65% have access to a bicycle; 86% registered in Bikeability level 0/1 (i.e., beginner)	Not reported
TfL Report (2017)	13289	724	42	76	43% 16–34, 46% 35–54, 11% > 55	68% have access to a bicycle	Not reported
Zander et al. (2013)	17	17	Not reported	71	49–72 (mean 61)	Sample is higher socio-economic status (SES) than national average	Not reported
Child Studies							
Ducheyne et al. (2014)	135[a]	130	Not reported	48	8–10 (mean 9.3, SD 0.5)	86% normal weight; 74% live < 3 km from school; 76% higher SES	Not reported
Groesz, 2007	830[a]	118	39	59	9–12 (mean 10.4, SD 0.6)	Mean BMI 20.36 (SD = 4.57)	11% (n = 9 intervention; n = 4 waitlist) never bicycle
Hatfield et al. (2015)	356[a]	136	Not reported	60	10–14 (mean 11.8, SD 1)	Not reported	6% (n = 7) of intervention group did not bicycle
Jones (2017)	Not reported	631	Not reported	52	74% 8–10, 26% 13–14	81% own bicycle	Not reported
Montenegro (2015)	Not reported	1575	70	45	8–12 (mean 10.2)	Not reported	15% (n = 240) did not know how to bicycle
van Lierop et al. (2016)	153	80	Not reported	44	10–11 (mean 11)	93% have access to a bicycle	4% never bicycle

[a] In studies with randomized control and quasi-experimental designs, study population size includes both children receiving intervention and children included in control/comparison group.
[b] Age ranges, means, and standard deviations listed if reported.
[c] Questionnaire item asked "When was the last time you rode a bike?".

et al., 2014). In one study, the net change in bicycling frequency was unclear as the parent and children-reported outcomes differed (van Lierop et al., 2016). Across studies data was not always reported out in a manner to enable calculation of standardized effect sizes (e.g., Cohen's d). For example, some studies reported percentage increases (e.g., Rissel and Watkins, 2014; Montenegro, 2015).

All studies assessed other outcomes in addition to the bicycling frequency, mostly about skills, knowledge, and confidence. Skills and knowledge were measured by questionnaire in several studies on children, with the exception of three studies that used direct observation by researchers (Ducheyne et al., 2014; Hatfield et al., 2015; Jones, 2017). Measures of confidence were typically taken from questionnaire responses. Eleven of the twelve studies measured confidence, and all found that confidence increased after the intervention. However, results for confidence do not necessarily align with results for bicycling frequency. One of the studies of adults found no bicycling increase, despite a confidence increase (Telfer et al., 2006). Similarly, one of the studies of children found that increases in children's confidence did not translate to increased bicycling to school (Groesz, 2007).

Additionally, several studies conducted subgroup analysis, analyzing bicycling increases by experience, training level, gender, or age. Four studies specifically assessed new bicycling from a baseline of zero. Of these, three examined changes in bicycling among those who said they had not bicycled at all or in recent years: one in adults found high rates of uptake 71% and 77% (at three and twelve month follow up) for those who had not bicycled at all or in recent years (Rissel and Watkins, 2014). In two of the studies on children, 9 of 74 had never bicycled and 56% started bicycling (Groesz, 2007), and 7 of 108 had never bicycled and 86% started bicycling (Hatfield et al., 2015). A fourth study considered only bicycling in the past week, and found that among the 55 of 113 participants who had not bicycled at baseline, there was a 40% increase at follow-up (Telfer et al., 2006).

A study that looked at training level found that bicycling increases were associated with higher levels of training (i.e., people were more likely to bicycle if they completed Levels 2 or 3 of Bikeability) (Johnson and Margolis, 2013). Transport for London (2016, 2017) examined bicycling frequency by gender and found that men were more likely to bicycle pre-intervention, but the bicycling gender gap narrowed post-intervention. One study (Jones, 2017) examined bicycling frequency by gender and age among children and found that both boys' and girls' bicycling to school increased post-intervention over a one year period, but the shape of their trajectories differed. Girls' increases peaked immediately post-intervention, whereas boys' increases were sustained over time. This study also compared three age groups: 8–9, 9–10, and 13–14 years, and found that increases in bicycling frequency among younger children were far greater than that of their teenage counterparts.

3.3. Descriptions of theory

Table 3 shows that no studies met all three indicators to fully explain the role of theory in developing the design or evaluation of the intervention, and only one study (Groesz, 2007) met two indicators. This study evaluated BikeTexas Safe Routes to School using Social Cognitive Theory, Theory of Planned Behaviour, and the Social Ecological Model. It hypothesized that the intervention facilitated behaviour change through knowledge (lessons component), motivation/intent (encouragement component), and self-efficacy (hands-on component), as well as aspects outside of each individual child. These extra-individual aspects included factors within the home (such as parental support), the school (such as teacher engagement with the program), and the neighbourhood (operationalized via perceptions of the neighbourhood environment).

Eight other studies mentioned predictors of bicycling behaviour in the introduction or methods sections. These are suggestive that some conceptual framework may have guided the intervention design. For example, (Telfer et al., 2006, p. 155) explained, "the [training] was designed to develop personal skills to facilitate behaviour change; it did not address societal, cultural, or environmental barriers", indicating that the intervention had been developed with specific targets. Given the limited description of theory, we are unable to describe any trends between reporting use of theory and increased bicycling frequency.

Table 3
Use of theory by bicycle skills training studies, assessed with Theory Coding Scheme (TCS).

Author, Year	TCS 1: Is an explicit theory mentioned?	TCS 2: Are predictors of target behaviour mentioned?	TCS 3: Is the intervention based on theory?	Overall: Is theory mentioned? (Total Y)
Adult Studies				
Johnson and Margolis (2013)	N	N	N	No (0/3)
Rissel and Watkins (2014)	N	Y	N	Partial (1/3)
Telfer et al. (2006)	N	Y	N	Partial (1/3)
TfL Report (2016)	N	N	N	No (0/3)
TfL Report (2017)	N	N	N	No (0/3)
Zander et al., 2013	N	Y	N	Partial (1/3)
Child Studies				
Ducheyne et al., 2014	N	Y	N	Partial (1/3)
Groesz, 2007	Y	Y	N	Partial (2/3)
Hatfield et al. (2015)	N	Y	N	Partial (1/3)
Jones (2017)	N	Y	N	Partial (1/3)
Montenegro (2015)	N	Y	N	Partial (1/3)
van Lierop et al. (2016)	N	Y	N	Partial (1/3)

Table 4
Context description of bicycle skills training studies.

Author, Year	Policy Setting	Extent of Infrastructure	Population Bicycling
Adult Studies			
Johnson and Margolis (2013)	London aims for 5% bicycle trips by 2026; funding through transport and health initiatives; congestion charge reduced driving	New bike share; 12 new bicycle highways; existing network	2% of trips
Rissel and Watkins (2014)	National funding for AustCycle training; little funding allocated for new bicycling infrastructure	Existing network, but little funding allocated for improvements	5% of Australians bicycle for transport
Telfer et al. (2006)	Not reported	Not reported	Under 2% commute trips
TfL Report (2016)	Mayor's aim is to double the number of people cycling in London by 2023	Not reported[a]	Not reported
TfL Report (2017)	Mayor's aim is to double the number of people cycling in London by 2023	Not reported[a]	Not reported
Zander et al. (2013)	City funded this and other bicycle skills courses for older adults	Not reported	18% of Australians over 50 bicycled in past year
Child Studies			
Ducheyne et al. (2014)	Not reported	Not reported	Not reported
Groesz (2007)	Federal funding provided for the Safe Routes to School programs in Texas	Large urban park network of paths (15 km)	Not reported
Hatfield et al. (2015)	School training aligns with national curriculum[b]	Canberra has one of the most extensive networks in Australia, with off-road paths, on-road bicycle lanes, etc.[b]	Not reported
Jones (2017)	Dungarvan awarded funding (€7.2 m) in 2012 for infrastructure and behaviour change programs, including school training	Well-connected bicycle network to schools, residences in Dungarvan; new infrastructure around schools during study; no infrastructure in Tramore	Under 2% children bicycle to school in Ireland; 4.5% of students of study area bicycled to school in 2013
Montenegro (2015)	CYCLE Kids program is mandatory in Massachusetts schools	Not reported	Not reported
van Lierop et al. (2016)	Not reported	Not reported	Not reported

[a] London bicycling infrastructure described in Johnson and Margolis (2013).
[b] Context reported in subsequent article Hatfield et al. (2017).

3.4. Descriptions of intervention context

The contextual effect of residing in a place with public policies and supportive infrastructure to encourage bicycling (Buehler and Pucher, 2012; Harms et al., 2016), where bicycling is viewed positively, and where there are higher rates of bicycling can influence people's perceptions and decisions to bicycle (Goetzke and Rave, 2010; Handy et al., 2014; Pucher et al., 2010). We found only 3 of the 12 articles (Table 4) provided this information on all three domains of context (Johnson and Margolis, 2013; Jones, 2017; Rissel and Watkins, 2014), while two provided partial descriptions (Groesz, 2007; Zander et al., 2013). One provided details in a subsequent article (Hatfield et al., 2017). Four of the bicycle skills training interventions were part of a broader bicycling promotion initiative accompanied by infrastructural investments (Johnson and Margolis, 2013; Jones, 2017; Transport for London, 2017, 2016). These four studies also reported increases in bicycling. One study reporting bicycling increases described an extensive network of already-existing bicycle routes (Hatfield et al., 2017), but other studies reporting increases did not describe infrastructure in the area (e.g. Rissel and Watkins, 2014). Given the limited description of context, we are unable to describe any trends or relationships between bicycling infrastructure, population-level bicycling prevalence, and bicycling increase.

3.5. Descriptions of intervention content

There was variation in intervention content and delivery (presence of road ride or not; provider qualification (accredited instructor, school teacher, etc); format (student teacher ratio); and duration) (Table 5) and no definitive patterns with increases in bicycling frequency emerged. Although all interventions included a hands-on component (an inclusion criteria of this review), not all included real-world context such as a road ride. Some studies have suggested that entirely traffic-free settings such as playground-only settings may not provide the same training experience as on-road settings (Macarthur et al., 1998). For this reason, some bicycle skill trainings incorporate a supervised road ride as part of the curriculum. Three of the six interventions with children involved a road ride, but only two were associated with increases in bicycling to school (Hatfield et al., 2015; Jones, 2017). Only one of the three interventions in a playground-only setting was associated with increases in bicycling to school (Montenegro, 2015). We were not able to assess how many adult participants had a road ride as part of their bicycle skills training in five studies where training was delivered in discrete progressive levels as neither these numbers, nor bicycling increases, were reported.

In terms of intervention format, adult trainings were delivered either in groups or one to one by accredited instructors; however,

Table 5
Intervention delivery descriptions outlined in bicycle skills training studies.

Author, Year	Intervention name	Intervention aims	Setting	Road ride component (y/n)[a]	Provider[b]	Format[c]	Duration[d]	Other
Adult Studies								
Johnson and Margolis (2013)	Bikeability	Increase skills, confidence for road travel; 'more people cycling, more safely, more often'	City-wide	Level 1: N Levels 2–3: Y	Accredited instructor	1:1 training; 3 levels of programs[e]	Up to 4 h	Free courses; program targets new or returning bicyclists
Rissel and Watkins (2014)	AustCycle	Increase number of cyclists, regular physical activity, skills, confidence, opportunities	Communities	Level 1: N Levels 2–3: Y Level 4: unknown	Accredited teachers	Student-teacher ratio not described; 4 levels of programs[f]	Not described	Free courses; program targets disadvantaged
Telfer et al. (2006)	–	Increase frequency, duration of bicycling, skills, confidence for leisure or commute	Community	Y	Bicycle coach	8:1 student to coach ratio[g]	6 h (2 × 3 h classes)	Free courses; program targets beginner and intermediate
TfL Report (2016)	Bikeability	See Johnson & Margolis above	City-wide	Level 1: N Levels 2–3: Y	Accredited instructor	Group or 1:1 training; 3 levels of program[e,h]	Not described[h]	Free & fee courses[h]
TfL Report (2017)	Bikeability	See Johnson & Margolis above	City-wide	Level 1: N Levels 2–3: Y	Accredited instructor	Group or 1:1 training; 3 levels of program[e,h]	Not described[h]	Free & fee courses[h]
Zander et al. (2013)	–	Develop cycling ability, safety, knowledge, confidence	Community	Y	Accredited trainers	Group lessons & 1:1 mentors	4.5 h	Program targets older adults
Child Studies								
Ducheyne et al. (2014)	–	Teach children to bicycle safely	Schools	N	Masters students trained for study	8:1 student to instructor ratio in class	3 h (4 × 0.75 h hands-on classes) over 4 weeks	Program included a practical skills test
Groesz (2007)	Safe Routes to School	Enable elementary and middle school students to walk and bicycle to school; improve safety	Schools	N	School teachers	Group in PE class	15 classes	No additional information
Hatfield et al. (2015)	Safe Cycle	Promote defensive riding skills; increase awareness to hazards; develop skills for risk management	Schools	Y	Not described	Group in PE class	8 classes (4 hands-on classes) over 8 weeks	No additional information
Jones (2017)	–	Increase bicycling to school	Schools	Y	Trained sports, exercise, & coaching students	Group in PE class	5 h (5 × 1 h hands-on classes) over 5 weeks	Program included practical skills test
Montenegro (2015)	CYCLE Kids	Provide physical activity skill, nutrition education	Schools	N	School teachers and police officers	Group in PE class	8 classes over 4 weeks	Program addresses nutrition and physical activity for health
van Lierop et al. (2016)	Certificat Cycliste Averti	Teach children how to become safer bicyclists	Schools	Y	School teachers and qualified Velo Quebec guide	Group in PE class	13 h (6h hands-on, 6 h theory, 1 h road ride)	Program included individual on-road exam

[a] Road ride defined as riding on the street compared to riding in traffic-free environment such as park, parking lot, or playground.
[b] Provider defined as the person who delivered the actual training to participants.
[c] All interventions had an on-bike practice component and off-bike skills/knowledge component.
[d] Duration defined as intervention length and/or number of sessions.
[e] Bikeability offers tiered training courses to address progressive ability level. Bikeability Level 1 teaches beginners to control bicycles in off-road environments; Level 2 teaches to bicycle on the road with light traffic for short journeys; Level 3 teaches negotiating a variety of road and traffic conditions. The training manual (Bikeability Delivery Guide) describes Level 3 as 1:1 format or small groups of 2–3 people bicycling on streets in participants' neighbourhoods.
[f] Austcycle offers tiered training courses to address progressive ability level. AustCycle Level 1 teaches beginners bike safety principles and bike handling skills; Level 2 teaches intermediate riders traffic awareness and safety skills in both traffic-free and low traffic conditions; Level 3 teaches advanced bike handling and traffic skills, starting on quiet roads and progressing to busier roads; Level 4 involves specialized coaching sessions and techniques for outdoor recreation purposes, on-road fitness and health programs, and advanced mechanical competencies.
[g] This study evaluated early pilot Austcycle courses and was consistent with Austcycle Level 1 and 2 (C. Rissel, personal communication, Oct 23, 2017).
[h] Transport for London provides funds to London boroughs to provide training to anyone who lives, works, or studies in their borough. For further details, we contacted Transport for London staff and learned that individual boroughs determine how to best spend funds. The format and duration of trainings were highly customizable, for example, training could be obtained in group or one to one sessions, for general or specific populations, and the number of sessions could vary, although sessions were a minimum of two hours in duration (L. Mountford, personal communication, Oct 25, 2017).

no articles provided subgroup analysis by delivery format. Five studies reported that participants without bicycles were provided with one by the program (Hatfield et al., 2015; Jones, 2017; Montenegro, 2015; Rissel and Watkins, 2014; van Lierop et al., 2016), while other studies made no explicit mention if participants used their own bicycles. While each adult session included on-bike practice, it was sometimes unclear how many of the school-based sessions included on-bike practice. All interventions with children were delivered in physical education class by teachers or university students trained to deliver the curriculum. The duration of bicycle skills training varied: for example, school-based interventions ranged between 3 and 13 h total, although we note no relationship between duration and observed change in bicycling. The duration of adult trainings was not described in three studies. Children's programs consisted of more sessions (e.g., 4–15 sessions) than those of adults. Finally, we also collated program aims. All but four bicycle skills training programs explicitly aimed to increase bicycling as a primary aim (Ducheyne et al., 2014; Hatfield et al., 2015; van Lierop et al., 2016; Zander et al., 2013). Of these four, one was not associated with increased bicycling (Ducheyne et al., 2014), and the results of another were unclear (van Lierop et al., 2016).

3.6. Descriptions of intervention behaviour change techniques

Only three studies (Ducheyne et al., 2014; van Lierop et al., 2016; Zander et al., 2013) provided sufficient detail to determine behavior change techniques from study descriptions. For other studies, authors obtained intervention training guides (Hatfield et al., 2015; Johnson and Margolis, 2013; Jones, 2017; Rissel and Watkins, 2014; Transport for London, 2017, 2016) or contacted study authors for more information (Telfer et al., 2006). We could not obtain further information on two studies (Groesz, 2007; Montenegro, 2015).

Table 6 documents behaviour change techniques (BCTs) (Michie et al., 2013) used in interventions. All interventions used the techniques of instruction on how to perform the behaviour (4.1), and on behavioural practice (8.1). Other common techniques were demonstration of the behaviour (6.1) and information about health consequences (5.1), and then graded tasks (8.7) and exposure (7.7). Goal setting (1.1) and problem solving (1.2) were only explicitly mentioned in the London-based advanced trainings, and only one study mentioned social support (3.1, 3.2). Only the Safe Routes to School intervention was explicit about incorporating encouragement (non-specific reward, 10.3) and changing social norms (social comparison, 6.2) as part of its design. Although this latter intervention was designed to include encouragement aspects such as Bike to School events and classroom competitions, in the actual implementation, encouragement was only implemented at one school (Groesz, 2007).

4. Discussion

With the goal of increasing active travel, there is growing interest among practitioners on the impact of bicycle skills training on increasing bicycle participation (Johnson et al., 2016; Johnson and Margolis, 2013; Rissel and Watkins, 2014). Our scoping review found 12 studies that focused on bicycle skills training in children and adults. The impact of bicycle skills training on bicycling frequency varied by study; however, the data does suggest that bicycle training programs can be effective in increasing bicycling levels. Most interventions were also effective in increasing confidence, which could encourage more bicycling. The studies inconsistently reported details about the intervention theory, context, and content. However, these details are crucial to assess the effectiveness of the intervention and its generalizability to other settings.

Almost all studies reported that bicycle skills training had some impact on increasing bicycling among participants. Of the 10 studies that specifically assessed bicycling for transportation, six found that bicycling to work or school increased after participating in an intervention. A higher proportion of adult studies (i.e., three of four) found increases in transportation bicycling than children studies (three of six). This trend is strengthened by the findings of a recent New Zealand children study (published in early 2018 after our literature search) which also found small but insignificant increases in bicycling to school post-intervention (Mandic et al., 2018). There are important distinctions to consider when comparing adult and children transportation bicycling. Adult participants self-select to attend a bicycling skills training, possibly because they are already motivated to increase bicycling (Garrard, 2015), whereas all children at schools participate. Furthermore, the determinants of active travel by bicycle between children and adults differ. For example, children's bicycling to school is also determined by parental attitudes and household travel schedules (Ahern et al., 2017; Mammen et al., 2012; McMillan, 2007). For this reason, some studies included in our review recommend that interventions to increase school active travel need to also directly target parents (Ducheyne et al., 2014; Groesz, 2007; Jones, 2017). Children's bicycling may also be shaped by policies specifying at which age children are allowed to use the bicycle unaccompanied (Shaw et al., 2015).

Half of the studies included subgroup analyses which looked at whether training programs had different effects by bicycling experience, gender, or age. Increasing overall bicycling rates in cities will require more people to begin bicycling, and women are an important target as there is a gender gap in bicycling participation rates (Mitra et al., 2016; Sahlqvist and Heesch, 2012). The review found not only that women tend to be overrepresented in bicycle skills training, but early data from one study suggests that training can narrow the participation gender gap (Transport for London, 2016). Amongst children, one study indicates that girls' bicycling may benefit from sustained encouragement, and bicycle skills training may have a greater impact delivered to children before the teen years (Jones, 2017). This finding aligns with other studies that have found gender differences in bicycling begin as early as the teen years (Emond and Handy, 2012; Handy, 2014; Teyhan et al., 2016; Wittmann et al., 2015). This suggests that not only is earlier delivery more effective, but warrants more study on the gendered longer-term impacts of bicycle training. It also signals that interventions should address gendered barriers and facilitators of bicycling for teen and adult women.

In studies with longer follow-ups or more time points, findings suggest that the impact of bicycling skills training on bicycling

Table 6
Behaviour change techniques (BCTs) used in the bicycle skills training interventions.

Author, Year	1.1 Goal setting	1.2 Problem solving	3.1 Social support (unspecified)	3.2 Social support (practical)	4.1 instruction on how to perform the behaviour	5.1 Information about health consequences	6.1 Demonstration of the behaviour	6.2 Social comparison	7.7 Exposure	8.1 Behavioural practice	8.7 Graded tasks	9.1 Credible source	10.3 Non-specific reward
Adult Studies													
Johnson and Margolis (2013[a]	X[c]	X[c]			X	X[d]	X		X[d]	X	X		
Rissel and Watkins (2014)[a]					X	X	X		X[c]	X	X		
Telfer et al. (2006)[b]					X	X	X			X	X		
TfL Report (2016)[a]	X[c]	X[c]			X	X[d]	X		X[d]	X	X		
TfL Report (2017)[a]	X[c]	X[c]			X	X[d]	X		X[d]	X	X		
Zander et al. (2013)			X	X	X		X			X		X	
Child Studies													
Ducheyne et al. (2014)					X		X			X			
Groesz (2007)					X	X	X	X[e]		X			X[e]
Hatfield (2015)[a]					X	X	X		X	X	X		
Jones (2017)[a]					X	X	X		X	X	X		
Montenegro (2015)					X					X		X	
van Lierop et al. (2016)					X	X	X		X	X	X		

X[c] = offered in Level 3 only.
X[d] = offered in Level 2 & 3 only.
X[e] = part of intervention design but not uniformly implemented.
[a] BCT content obtained through training manual.
[b] BCT content confirmed with study author.

frequency is not always maintained, but that increases reported immediately post-intervention declined with time (Hatfield et al., 2015; Jones, 2017; Rissel and Watkins, 2014). To help sustain behaviour change, some study authors recommend that bicycle skills training could be followed by post-training support to ensure that participants consolidate the skills and confidence gained during the intervention (Hatfield et al., 2015; Jones, 2017). It may also be important to examine the factors influencing the maintenance of bicycling over time, for example, distance to destination, or participant perceptions about convenience of bicycling (Panter et al., 2013a, 2013b). The literature on behaviour change maintenance suggests that interventions be coupled with broader changes to social and physical environments to sustain long-term effects (Kwasnicka et al., 2016; Ory et al., 2010).

Our review examined associations between intervention theory, context, content, and changes in bicycling frequency. The use of theory has been advocated to aid both intervention design and evaluation. Theory aids researchers to measure and describe pathways of behaviour change (Bartholomew and Mullen, 2011), and theory can also help explain why some interventions work in certain settings and not others (Howarth et al., 2016). Theory explicitly identifies what the core intervention components and causal mechanisms of change are thought to be and how the intervention intends to achieve the desired behaviour change (Davis et al., 2015; Kok et al., 2016; Rothman, 2004). Only one of the studies explicitly described underpinning theory, conceptual models, or mechanisms of change; a finding echoed in other active travel reviews (Chillón et al., 2011). However, most studies did name individual-level determinants of bicycling (e.g., confidence, attitudes, safety knowledge, etc.) and measured these, which implies that interventions were based on implicit assumptions about how the program was expected to achieve its objectives. Without explicit theory, we were unable to gain insight as to why only certain behaviour determinants were targeted in the intervention, and how this may have limited the intervention's effectiveness.

Our scoping review found that context was described in half the articles. Context descriptions are essential for understanding why and for whom interventions are effective, and are needed to replicate and build on research findings (Shoveller et al., 2016). Researchers are urged to report more thoroughly on the context of interventions, yet given the cursory treatment of context in many studies it would appear that defining and describing context is a challenge. This is possibly due to the broad range of how context is defined and what can be considered as relevant (Datta and Petticrew, 2013; Howarth et al., 2016; May et al., 2016; Pfadenhauer et al., 2015). To aid context description, Pfadenhauer et al. (2017) suggest reporting context at different scales (from local community to national to international) in up to seven domains, of which we assessed the three that have most often appeared in the bicycling literature: political, geographical, socio-cultural context. We looked for mention of government policies to encourage bicycling; characteristics of the built environment to encourage bicycling (specifically investment in bicycling infrastructure); and population bicycling prevalence as a proxy for social norms of the acceptability of bicycling. We recommend study authors report more details on at least these three contextual elements relevant to active travel behaviour change. Our bicycling prevalence measure is possibly too simplistic for some. More thorough description of socio-cultural context includes discourses, meanings, and norms of bicycling (Aldred and Jungnickel, 2014; Nettleton and Green, 2014; Sherwin et al., 2014). Other researchers also recommend reporting socio-spatial information such as density, land use diversity, and demographic characteristics of intervention areas (Harms et al., 2016). Study authors could also describe other known determinants of bicycling, such as topography. Bicycle skills trainings target individual-level predictors of behaviour such as skills, confidence, knowledge, and attitudes, but these are also shaped by contextual elements (such as cultural or legal standards for children's independent mobility, or societal perceptions on using bicycles for daily travel) which in turn influence how easily participants are able to shift and sustain behaviour.

Encouraging active travel by bicycle entails targeting determinants beyond the individual level. Bicycling is sensitive to context and practitioners must consider place-based characteristics such as policy, infrastructure, or bicycle culture. Several study authors in our review commented that bicycle skills training needs to be part of a coordinated and multi-faceted approach to encourage bicycling (Ducheyne et al., 2014; Jones, 2017; Rissel and Watkins, 2014; Telfer et al., 2006). Experts have suggested that infrastructure and training can act synergistically and have recommended comprehensive packages of integrated and complementary interventions to boost bicycling (Dill et al., 2014; Pucher et al., 2011, 2010; Pucher and Buehler, 2009; Thigpen et al., 2015). Such packages include changes to the physical and social environment (contexts) through bicycle infrastructure, policies, and promotion (Kandt et al., 2015). In our review, four bicycle skills training interventions were described as part of a comprehensive package undertaken by government where policies and infrastructure to promote active travel were supplemented with bicycle skills training. These were also interventions that showed increased bicycling among participants.

We described bicycle skills training intervention content by collating program activities and delivery details across studies and by coding for behaviour change techniques (BCTs). In the BCTs we were able to code, the most commonly used in bicycle skills training interventions were behavioural practice, instruction on how to perform the behaviour, demonstration of the behaviour, information about health consequences, graded tasks, and exposure. We did not find any other reviews on BCTs specific to bicycling. However, a few cover walking and cycling, or just walking. Bird et al (2013) found that for walking and bicycling interventions in adults, the most effective active travel interventions tended to include the BCTs of feedback and monitoring, and goals and planning (Bird et al., 2013). A review of walking interventions among children and adolescents found had the same BCTs were associated with effective programs, as well as social support, and repetition and substitution (Carlin et al., 2016). While BCTs effective in increasing walking may not be the same as for increasing bicycling (for example, the strong emphasis on behavioural practice may not be necessary in walking interventions), and it is also possible that the behaviour change techniques for increasing bicycling in different populations (such as children and adults) may differ. To facilitate behaviour change, interventions must have clear aims (e.g., to specifically increase bicycling *to school*, not just to increase bicycling skills). For example, the authors of one study that failed to increase bicycling to school noted that to influence mode shift, their intervention might have incorporated different strategies to target different determinants (Ducheyne et al., 2014).

The small number of studies returned by our search is not an unexpected finding: overall, there appear to be few studies assessing

adult bicycle skills training, and even fewer studies that measured bicycling frequency as an outcome in either adults or children. This paucity has been noted by other researchers (Pucher et al., 2011; Richmond et al., 2013). In many countries, bicycle skills training tend to be delivered by bicycling advocacy organizations, where funding may be directed toward service delivery rather than evaluation. Furthermore, with no universal school-based bicycle skills training delivered to children in most countries, systematic data collection or evaluation is unlikely to occur.

4.1. Strengths and limitations

This scoping review addressed an evidence gap on the impact of bicycle skills training on bicycling frequency (Goodman et al., 2016; Johnson et al., 2016), and further, extracted information on intervention theory, context, and content to describe variation in bicycling change within and between studies. Another strength of our study was the inclusion of grey literature, which gave us access to a broader range of evaluations that have been conducted and enabled us to include studies that added new information on gender-specific changes in bicycling. Our review looked at studies incorporating a pre-and post-test design so we could assess individual-level changes in bicycling frequency. This complements other literature that examines people's narratives of participating in a bicycle skills training program. One challenge we faced was the diverse ways that researchers measure bicycle frequency, making it challenging to directly compare intervention effects. Such heterogeneity in bicycling research has been noted elsewhere (Bird et al., 2013; Ogilvie et al., 2004; Pucher et al., 2010; Stewart et al., 2015; Yang et al., 2010). Another challenge was that we did not have sufficient data to code BCTs in all studies, despite contacting authors of the articles. With this lack of data, we are unable to attribute the impact of individual BCTs to bicycling outcomes. Furthermore, to respond to the transportation targets set by many cities, we restricted our search strategy to interventions encouraging *transportation* bicycling rather than bicycling more broadly (limiting studies using stationary or pool/aqua bicycles, or studies on elite athletes). Finally, we limited our search to English publications.

4.2. Implications for policy and practice

This review suggests that bicycle skills training may be a useful strategy for increasing bicycling participation. Specific opportunities to increase bicycling may be to target new and infrequent cyclists, especially women. Children are also an important target population, and training may have larger impact when delivered before the teen years. Additionally, interventions may benefit from incorporating follow-up support for trainees to help sustain their bicycling. Local governments may see maximum bicycling increases by designing a comprehensive package of interventions that includes supportive infrastructure and bicycle skills training, among other promotional efforts.

To generate a more rigorous evidence base on the sustainability of any impacts, a methodological recommendation is to include multiple follow-up measures to assess bicycling trajectories, as well as adequate follow-up periods to allow changes in bicycling to occur. A second methodological recommendation is to incorporate comparison populations (i.e., people who do not receive the intervention) to control for weather/seasonality, children's maturation, or other factors affecting cycling (Harris et al., 2006). A third recommendation, to enable comparison of effect sizes between studies (e.g., using Cohen's d), is for study authors to report standard deviations for proportions.

Future training interventions should consider reporting explicitly on theory, context, and content. Numerous tools or frameworks such as the Theoretical Domains Framework/Behaviour Change Wheel (Michie et al., 2011; see also www.behaviourchangewheel.com), Intervention Mapping (Kok et al., 2016), or realist evaluation (Pawson and Tilley, 1997) have been developed to support theory-driven approaches. A theory-driven approach to intervention design and evaluation explicitly maps out the process of *how* changes in bicycling frequency will be achieved through bicycle skills training, and this can help identify the appropriate content and behaviour change techniques to be applied. This may be especially salient for addressing barriers that go beyond skills-based consideration. A theory-driven approach can also account for the ways in which bicycle skills training interacts with its contexts. This helps improve the quality of bicycle skills training (e.g., to be more responsive to the needs of target populations); explain why changes are higher or low than expected; assist with scale-up; and inform policy-makers what further actions need to be taken to enable people to adopt bicycling.

5. Conclusions

This is the first review that examines bicycle skills training and changes in bicycling frequency. The main finding is that bicycle skills training is generally associated with increased bicycling, but the number of studies are small and of mixed quality. Future studies should also report adequate details about the intervention theory, context, and content, so that it may be generalizable for use in other settings. Such reporting would also allow for better implementation in policy and practice. Further, studies need to incorporate more rigorous study designs that include multiple points of follow-up, and with comparison groups if possible. Subgroup analysis between genders, non-bicyclists and current bicyclists, content (e.g., off- and on-bike components such as road-rides), or programs implemented in different contexts may further advance insights into for whom training programs are most effective in terms of increasing bicycling. Such details are important to guide other practitioners on training design and implementation.

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