What is the best way to promote cycling? A systematic review and meta-analysis

Onur Cem Dogru, Thomas L. Webb, & Paul Norman

The University of Sheffield, UK

Direct correspondence to: Onur Cem Dogru, Department of Psychology, The University of Sheffield, Cathedral Court, 1 Vicar Lane, Sheffield, UK. Email: ocdogru1@sheffield.ac.uk

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Abstract

Cycling has the potential to address a number of personal and societal challenges, not least with respect to health and the need for more sustainable modes of transport. However, the best way(s) to promote cycling is still unclear. In an effort to answer this question, we identified 39 interventions designed to promote cycling, with a total sample of 46,102 participants. Random effects meta-analysis estimated a small but statistically significant effect of interventions on cycling behaviour ($g_{+} = 0.14$, 95% CI [0.05, 0.23]). To identify the most effective intervention strategies, we coded the behaviour change techniques used within each of the interventions. Interventions that prompted people to self-monitor their behaviour or added objects to the environment (e.g., provided shared bikes) were more effective than those that did not use these strategies. Interventions that restructured the physical environment (e.g., built new cycle paths) were less effective than the studies that did not do this. We also identified a number of factors that moderated the effect of the interventions on outcomes; specifically, interventions that targeted a specific group, used objective measures of cycling such as accelerometers, and that were tested using independent groups designs typically yielded stronger effects. The findings should help to guide interventions to promote cycling in the future.

Keywords: Cycling, sustainable transport, behaviour change techniques, intervention, meta-analysis

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Cycling is widely encouraged as a sustainable mode of transport (McDonald, Yang, Abbott, & Bullock, 2013; Pucher, Dill, & Handy, 2010; Spotswood, Chatterton, Tapp, & Williams, 2015) that also benefits health by increasing levels of physical activity (Warburton, Nicol, & Bredin, 2006). Globally, more than half of all trips are shorter than 5 kilometres, yet only 1 to 2% of all trips are made by bicycle (Pucher, & Buehler, 2008; Pucher, Buehler, & Seinen, 2011; Department for Transport [DfT], 2018). Promoting cycling has attracted attention from different disciplines such as city and regional planning, civil engineering, public health, and psychology. However, the success of efforts to promote cycling varies and likely depends on the specific strategies used. We therefore aimed to review the evidence to date to identify the best way to promote cycling.

Strategies that have been used to promote cycling include improving the physical environment and infrastructure, as well as strategies targeting individuals' beliefs about cycling (e.g., persuasive messages about the health benefits), skills, or opportunities, or combinations of these approaches. For example, interventions have built segregated and connected bicycle paths or traffic free trails, landscaped these paths (e.g., painted trails with visible colours and planted the surroundings), added bicycle parking racks to destination points, or improved traffic signs (Dill, McNeil, Broach, & Ma, 2014; Goeverden, Nielsen, Harder, & Nes, 2015). Interventions have also taught people how to cycle, provided information about new routes and safety requirements, provided incentives to those who cycle, and arranged social activities around cycling (Bourdeaudhuij et al., 2010; Ducheyne, Bourdeaudhuij, Lenoir, & Cardon, 2014; Goodman, van Sluijs, & Ogilvie, 2016; Mantzari et al., 2015; Petrunoff, Rissel, Wen, & Martin, 2015; Petrunoff, Wen, & Rissel, 2016; Teyhan, Cornish, Boyd, Joshi, & Macleod, 2016).

However, interventions vary in how effective they are in promoting cycling and, in some cases, ostensibly similar interventions can yield different results. For instance, Ducheyne et al. (2014) found that participants who received an intervention designed to teach people how to cycle actually cycled less (not more) than participants in a control group. In contrast, Goodman et al. (2016) found no difference between groups who were taught versus not taught how to cycle, and Teyhan et al. (2016) found significantly higher rates of cycling among participants who were taught to cycle than those who were not taught. Similarly, improving the infrastructure for cycling has had mixed results (e.g., Brown et al., 2016; Burbidge & Goulias, 2009; Dill et al., 2014). Therefore, it is necessary to estimate the effect of interventions to promote cycling across different studies and, more importantly, identify what features of the interventions, studies, or samples, account for the heterogeneity in results so that these can be used to improve future interventions.

Previous Reviews

A number of prior reviews have synthesized evidence on promoting active travel (e.g., de Nazelle et al., 2011; Mantzari et al., 2015; Panter, & Jones, 2010; Petrunoff, Rissel, & Wen, 2016; Scheepers et al., 2014), but few of them have focused specifically on cycling. For example, Yang, Shalqvist, McMinn, Griffin, and Ogilvie (2010) systematically reviewed 25 interventions. However, only six of the included studies specifically targeted cycling (16 targeted “environmentally friendly” modes of transport, and three targeted travel behaviour in general). Of the six studies that specifically targeted cycling, two were population level studies, which reported net increases in the prevalence of cycling across a population. The other four also reported significant improvements in cycling rates but on a smaller scale; one distributed free bikes and prescribed physical activity to women with abdominal obesity, one improved cycling infrastructure, and two were multifaceted initiatives (e.g., included promotional campaigns, infrastructure changes, personalized travel planning, bicycle repair services, etc.).

In another review, Pucher et al. (2010) identified 139 interventions that were designed to promote cycling (including interventions targeting active travel in general that measured effects on cycling separately). Pucher et al. divided the interventions into five categories; namely, those providing travel-related infrastructure, end-of-trip facilities (such as sheltered parking, storage, repair, showers, etc.), transit integration programs, bike share schemes, and/or cycling related laws. However, it was not always clear which of the intervention strategies were effective (or not) because some of the interventions incorporated multiple strategies (e.g., a network of bike lanes was extended while also introducing a new bike share scheme and adding extra bicycle parking docks, etc.). As a result, it is difficult to identify the 'active ingredients' of the interventions (Craig et al., 2008) and understand why and how they are (or are not) effective from the previous reviews.

One notable exception is a review by Bird et al. (2013) which identified the Behaviour Change Techniques (or BCTs) that were used by interventions designed to promote active travel (defined as walking and cycling). Bird et al. identified 46 studies targeting walking and/or cycling and found that 21 (46%) reported statistically significant effects of the intervention on these behaviours. The most frequently used BCTs among interventions that had a statistically significant effect were prompting self-monitoring and prompting intention formation (both were used in 13 out of the 21 interventions that had statistically significant effects). Bird et al. also reported that the number of BCTs used in interventions was not associated with how effective they were, which could suggest that multifaceted interventions are not necessarily more effective in promoting cycling than simpler interventions. Again, however, while these findings are useful, from the perspective of identifying how best to promote cycling they are limited because 30 of the 46 studies included in the review focused only on promoting walking, while the remaining 16 studies tried to promote both walking and cycling. This means that none of the studies specifically targeted cycling. Furthermore, Bird et al. used an older taxonomy of 26 BCTs (Abraham, & Michie, 2008) to code the content of the interventions, which has now been updated to include 93 techniques (Michie et al., 2013).

It is also important to note that none of the previous reviews have used a meta-analytic approach to estimate the average effect of the interventions and to quantitatively examine which intervention strategies and features are reliably associated with smaller or larger effect sizes. Using such a quantitative approach offers a number of advantages such as being able to compare effect sizes of different interventions, compute precise effects of certain intervention strategies (e.g., infrastructural, psychosocial, or combined), and identify factors that moderate the effect of interventions on outcomes (Johnson, & Hennessy, 2019).

The Present Review

The present review aimed to answer the question of how best to promote cycling. This was achieved by addressing three shortcomings of previous reviews. First, we identified and reviewed studies that measured the effect of interventions on cycling (specifically), rather than effects on active travel (e.g., walking and cycling reported together). Even though both walking and cycling can be considered forms of active travel, they are inherently different means of transport. Walking requires (almost) no preparation or equipment and can be easily adopted for short distances, whereas cycling requires a bicycle (along with a safe and free space to keep it at destination points), and equipment such as a helmet or reflective clothing, particularly in countries or states where they are mandatory (de Jong, 2012; Pucher et al., 2011). These differences between cycling and other forms of active travel might decrease the accuracy of implications taken from a review of interventions that target both walking and cycling. Second, we coded the behaviour change techniques used by the interventions using a newer version of the BCT Taxonomy (v1: Michie et al., 2013), which includes a greater number of BCTs. Third, we used meta-analysis to estimate the effectiveness of specific intervention strategies in promoting cycling. This approach also allowed us to identify factors that moderate the effectiveness of interventions.

What factors might moderate the effectiveness of interventions to promote cycling?

In addition to the nature of the intervention (e.g., the specific strategies used to promote cycling), the effectiveness of interventions is likely to depend, in part, on characteristics of the sample, study design, measured outcomes, and/or other methodological features. The present review therefore aimed to identify potential moderators in an effort to account for variability in the effect of interventions designed to promote cycling on outcomes. Demographic factors such as age, gender, ethnicity, and education have been shown to be associated with cycling. For example, evidence suggests that older people and females cycle less in countries with low rates of cycling (Brujin et al., 2005; Liao, 2016; Ma, & Dill, 2015; Sener, & Lee, 2017), as do those without higher education (Belanger-Gravel et al., 2016; Braun et al., 2016). Methodological characteristics such as the length of the intervention, the way that participants were recruited, and randomization may also be associated with the effectiveness of different interventions. For example, Kang, Marshall, Barreira, and Lee (2009) found that the length of the intervention was positively associated with the effect of pedometers on physical activity. Finally, there are mixed findings with respect to whether using theory when designing and/or implementing interventions influences how effective they are (Garnett et al., 2018; Prestwich et al., 2014). We also aim to address this question in relation to promoting cycling.

Method

Selection of Studies

We used four inclusion criteria to select studies for the current review. First, studies had to include an intervention designed to promote cycling. Second, studies had to adopt an experimental design either with a pre- and post-intervention measure (i.e., a repeated measures or within-participants design), or include a control group that was exposed to little or no intervention (i.e., an independent groups design). Third, studies had to measure cycling, rather than active travel or physical activity in general. Cycling could be measured in terms of frequency, distance, or time, but not in terms of performance (e.g., speed, force). Finally, studies had to report sufficient detail for us to be able to compute an effect size representing the effect of the intervention on cycling.

Potential studies were identified using Web of Science with the “all databases” option selected using eight search keywords, organised into two filters – one for cycling (cycl* OR bicycl* OR bike*) and one for interventions (intervention OR trial OR experiment OR behavi* change strateg* OR random* control* trial*). The database search was undertaken on 30th January 2020. Combinations of “cycl*” with intervention keywords yielded 475,555 hits. We screened the first 1,000 hits rank ordered by the number of citations, but none of the studies were relevant (the studies were predominantly from biology, chemistry, and medicine). Given the unmanageable number of records returned by this particular combination of search terms, we decided to remove the keyword “cycl*” from the search terms. The remaining combination of keywords yielded 13,384 records (11,162 after duplicates removed).

Figure 1 shows the flow of information through the review. The titles and abstracts were first screened to decide whether the studies were likely to meet the inclusion criteria (i.e., described an intervention designed to promote cycling). The full texts of 335 studies that potentially met the inclusion criteria were then examined in detail by the first author, and 35 studies published in peer reviewed journals were included. In an effort to identify unpublished studies, we sent emails to 46 authors who contributed to the studies identified by the database search. Only one author replied with two possible reports, but neither were included because an effect size could not be computed from the statistics reported. We also searched the ProQuest database with the same combinations of keywords as described above in an effort to identify theses evaluating the effect of interventions designed to promote cycling. Thirty-eight records were identified, and one thesis proved suitable for inclusion (Groesz, 2007). Backward and forward reference searches were also conducted with the studies included and two additional unpublished studies were identified from this search. In total, we included four unpublished studies together with a previous intervention that we conducted, meaning the present review included 39 unique studies. Table 1 summarises the characteristics of the studies included in the review.

Data Extraction

We coded the following methodological characteristics of each study: (a) bibliographic information (e.g., author, year of publication, publication status); (b) study design (e.g., independent groups posttest only, single group pretest-posttest, or independent groups pretest-posttest; the number of conditions); (c) the outcomes measured for cycling (i.e., time, distance, and/or frequency), (d) the nature of the measure of cycling (self-report or objective); and (e) aspects of study quality (e.g., randomization, whether the researchers and/or the participants were blind to conditions, representativeness of the relevant population).

We also coded the following sample characteristics: (a) the mean age of the participants (in years); (b) the percentage of females in the sample; (c) the ethnicity of the sample (e.g., percentage white, black, Asian); (d) the modal level of education (no formal education, primary school, high school, undergraduate degree, postgraduate degree); (e) the country in which the study was conducted; and (f) the type of sample (e.g., children and adolescents aged below 17, general public, a specific group of adults such as employees in a specific company, patients of a specific disease, university staff and students).

Finally, we coded the following characteristics of the interventions: (a) the length in days; (b) the behaviour change techniques used; and (c) whether the intervention was guided by theory.

Effect size calculation/Meta-analytic Strategy

Cohen's *d* was used as an index of effect size, which reflects the standardized difference between two means (e.g., mean scores on a measure of cycling for experimental vs. control groups or the mean before vs. after an intervention). Where possible, we calculated this effect size using the means and standard deviations reported in the paper for the measure of cycling. When these statistics were not reported, we converted other statistics (e.g., odds ratios or chi-square) to Cohen's *d* using Psychometrica (www.psychometrica.de). Where relevant data was reported at multiple follow-up points, we used the data reported at the longest follow-up, both to provide a conservative estimate of the effects of the intervention and to focus on long(er) term changes in cycling, rather than immediate effects. Where studies reported the effects of an intervention on multiple relevant outcomes (e.g., how far participants cycled as well as how frequently they did so), we computed effect sizes for each outcome separately and then averaged them before inclusion in the main analysis. Meta-Essentials version 1.4 (Suurmond, van Rhee, & Hak, 2017) was used to compute the sample-weighted average effect (Hedges g_+) of the interventions on cycling, adjusting effect sizes from studies with different methodologies using the procedures described by Morris and DeShon (2002). Three of the studies (Goodman, Panter, Sharp, & Ogilvie, 2013; Hosford et al., 2019; Krizek, Barnes, & Thompson, 2009) had very large samples (i.e., > 3 *SD* from the average sample size), so we “winsorized” these sample sizes to the next largest one within the “normal” range, so as not to bias the overall effect size.

Results

Meta-analysis of 48 effect sizes from 39 unique studies and a total sample of 46,102 participants indicated that, on average, interventions designed to promote cycling have a small, but statistically significant (positive) effect on cycling ($g_+ = 0.14$, 95% CI: 0.05 to 0.23). Cochrane’s Q was statistically significant ($Q = 501.15$, $p < .001$) suggesting that the effect sizes were heterogeneous and the I^2 statistic indicated that a large proportion of the variance in the effect sizes was explained by this heterogeneity ($I^2 = 90.62\%$), which indicates a need to identify variables that account for the variability. Table 2 reports the effect of intervention, sample, and methodological moderators on the effectiveness of the interventions.

Does the nature of the intervention influence effect sizes?

The 48 interventions described by the primary studies included 24 unique behaviour change techniques (BCTs; see Table 2). The most frequently used techniques were restructuring the physical environment (BCT 12.1; e.g., building segregated bicycle lanes; used in 38% of interventions), instruction on how to perform the behaviour (BCT 4.1; e.g., instruction on how to change gears in a cycling course[1]; used in 33% of interventions), demonstration of the behaviour (BCT 6.1; e.g., demonstration of hand-signals; used in 27% of interventions), and behavioural practice/rehearsal (BCT 8.1; e.g., practicing steering; used in 27% of interventions). Three BCTs were associated with significant differences in the effect of the interventions that used (vs. did not use) them on cycling. First, interventions that prompted self-monitoring of behaviour (BCT 2.3; e.g., asked participants to use a smartphone app to track the distance or frequency with which they cycled) were significantly more effective (Hedges’ $g_+ = 0.48$, $k = 4$) than those that did not prompt participants to self-monitor their behaviour (Hedges' $g_+ = 0.12$, $k = 44$), $Q = 8.50$, $p = .004$. Second, interventions that added objects to the environment (BCT 12.5; e.g., placed bike parking racks near university buildings) were more effective (Hedges' $g_+ = 0.45$, $k = 7$) than those that did not use this technique (Hedges' $g_+ = 0.08$, $k = 41$), $Q = 14.72$, $p < .001$. Third, interventions that restructured the physical environment (BCT 12.1; e.g., built segregated bicycle lanes) were significantly less effective (Hedges' $g_+ = -0.01$, $k = 18$) than those that did not (Hedges' $g_+ = 0.24$, $k = 30$), $Q = 18.16$, $p < .001$). The number of BCTs used in the interventions was not significantly associated with the effect of the interventions on cycling ($\beta = 0.005$, $p = .682$). Finally, there was no evidence that interventions that used theory to guide their intervention (Hedges' $g_+ = 0.17$, $k = 9$) yielded significantly larger effects than interventions that did not use a theory (Hedges' $g_+ = 0.13$, $k = 40$), $Q = 0.42$, $p = .517$ (see Table 3).

Methodological moderators

With respect to methodological moderators, the nature of the measure of cycling and the design of the study significantly moderated the effect of the interventions on outcomes (see Table 3). Specifically, interventions typically had a larger effect on objective measures of cycling (e.g., accelerometers; Hedges' $g_+ = 0.37$, $k = 11$) than on self-report measures (e.g., online surveys; Hedges' $g_+ = 0.09$, $k = 37$), $Q = 6.72$, $p = .010$. Furthermore, studies that used an independent groups posttest only design typically reported larger effect sizes (Hedges' $g_+ = 0.27$, $k = 9$) than those that used an independent groups pretest-posttest design (Hedges' $g_+ = 0.12$, $k = 33$) or a single group pretest-posttest design (Hedges' $g_+ = 0.01$, $k = 6$), $Q = 7.93$, $p = .019$.

Sample moderators

We also tested whether characteristics of the sample moderated the effect of the interventions on cycling (see Table 3). Only the type of sample had a significant impact on the effectiveness of the interventions. Specifically, interventions targeting a specific group of adults (e.g., employees in a company, patients of a specific disease, university staff and students) were more effective (Hedges' $g_+ = 0.33$, $k = 10$) than interventions targeting children (Hedges' $g_+ = 0.16$, $k = 13$) or members of the general public (Hedges' $g_+ = 0.07$, $k = 25$), $Q = 6.99$, $p = .030$. Age ($B = -0.002$, $p = 0.577$), gender ($B = -0.380$, $p = 0.188$), modal level of education ($Q = 0.15$, $p = 0.985$), ethnicity ($B = -0.248$, $p = 0.244$) did not moderate the effectiveness of the interventions[2].

Discussion

The present review sought to identify the best way to promote cycling by quantitatively synthesizing evidence on the effectiveness of interventions designed to promote cycling. A systematic search identified 39 interventions that targeted cycling, providing 48 unique effect sizes. On average, the interventions had a small, but positive effect on cycling ($g_+ = 0.14$) confirming that it is possible to change people's cycling behaviour. Although the effects of interventions designed to promote cycling are typically small, it is important to recognise that interventions that produce small effects can have a large impact on public health if they can be scaled up and delivered at a population level (West, 2007). As expected, however, there was large variation in effect sizes from the primary studies. Part of this variability was accounted for by the nature of the intervention, with evidence that three BCTs influenced the effectiveness of interventions designed to promote cycling. Specifically, interventions that prompted participants to self-monitor their cycling behaviour and added objects to their environment such as bike parking racks or shared bikes were more effective than interventions that did not include these strategies, while interventions that restructured the physical environment were typically less effective than those that did not.

The effectiveness of self-monitoring in promoting physical activity is well supported (Bird et al., 2013; Conn, Valentine, & Cooper, 2002; Davies, Spence, Vandelanotte, Caperchione, & Mummery, 2012; Michie et al., 2009; O'Brian et al., 2015), as is the effect of prompting people to monitor their goal progress more generally (Harkin et al., 2016). Self-monitoring is also effective in promoting other health related outcomes such as weight loss (Burke, Wang, & Sevick, 2011), and reducing alcohol consumption (Crane, Garnett, Michie, West, & Brown, 2018). That the current review found that prompting self-monitoring helped to promote cycling is therefore consistent with evidence in other domains. The central role of self-monitoring in promoting goal attainment is highlighted by Control Theory (Carver & Scheier, 1982; 2002) in which self-monitoring is viewed as the process by which people compare their current state (or rate of progress) to their desired state and direct their next steps accordingly (e.g., try to cycle more). It is also worth noting that combining self-monitoring with other BCTs targeting self-regulatory processes specified by Control Theory, (e.g., goal-setting and action planning), should yield even larger intervention effects, as reported in a meta-analysis of healthy eating and physical activity interventions (Michie et al., 2009).

Relatively few reviews to date have considered the impact of adding objects to the environment on behaviour. In relation to cycling, this BCT includes increasing access to bikes via bike share schemes or adding bike parking racks. Such interventons might serve as cues to cycle, especially for those who do not own a bicycle or those who are unsure where they might park their bicycle. Evidence suggests that cues can help to develop habits (Lally, & Gardner, 2013), which reflect automatic responses to situational cues (e.g., the availability of a bike share scheme) and have been found to be strong determinants of travel behaviour in general, and cycling specifically (de Bruijn et al., 2009; Willis, Manaugh, & El-Geneidy, 2015). In short, interventions that add objects to the environment might be effective because they increase cues to cycle.

The finding that interventions that restructured the physical environment were less effective than those that did not restructure the environment was surprising. In relation to cycling, this BCT included changes to infrastructure (e.g., building new bicycle paths, landscaping lanes) and several previous reviews have reported positive effects of such interventions (Fraser & Lock, 2010; Pucher et al., 2010; Pucher et al., 2011). One possible reason for this difference between the findings of previous reviews and the current meta-analysis might be the challenges associated with quantifying the effects of studies that change infrastructure as they do not typically recruit participants and measure outcomes. As a consequence, it is difficult to control who is exposed to the intervention and obtain direct measures of outcomes. Alternatively, the present findings might suggest that psychosocial interventions (e.g., those prompting participants to keep track of how much they cycle) are more effective in promoting cycling than interventions that modify the infrastructure. While an infrastructure that supports cycling makes it easier to cycle, many people cycle despite the lack of, for instance, segregated bicycle lanes or traffic-free bicycle paths and, in turn, there are people who do not cycle despite the best infrastructure (Diniz et al., 2015; Nehme, Perez, Ranjit, Amick, & Kohl, 2016). Hence, projects aiming to improve the infrastructure might incorporate psychosocial components in their interventions alongside the changes to infrastructure.

It was interesting to note that only 24 of the 93 BCTs described by the BCT v1 taxonomy (Michie et al., 2013) have been used in interventions designed to promote cycling to date. This suggests that there is considerable scope for considering new ways to promote cycling that may not have been tried (or at least evaluated) previously. For instance, only one study in the present review prompted participants to set behavioural goals; however, goal setting has a small, but robust effect on behaviour (for a review, see Webb & Sheeran, 2006) and so might help to promote cycling together with BCTs targeting other processes from

Control Theory (e.g., goal monitoring and goal operating) as suggested by Michie et al. (2009). It is also possible that other combinations of BCTs may be effective. For example, Pucher et al. (2010) suggested that comprehensive programs with multiple active ingredients typically have larger effects on cycling. However, it may not be a case of simply using as many techniques as possible (indeed, we found that the number of BCTs used by interventions was not associated with efficacy) but rather using the right combination of techniques to promote cycling, where the 'right' combination is informed by relevant theory (Prestwich, Webb, & Conner, 2015).

Methodological moderators

Two methodological variables moderated the effect of the interventions on cycling – the way that cycling was measured and the design of the study. Firstly, interventions that used objective measures of outcomes typically reported larger effects than interventions that used self-reports. One interpretation is that objective measures provide a more accurate assessment of the effects of an intervention, since self-report measures can be biased and/or inaccurate (Podsakoff, MacKenzie, Lee, & Podsakoff, 2012; Podsakoff, & Organ, 1986). Finding that objective measures yield possibly more accurate results is also encouraging for future interventions, especially with the increased prevalence of smartphones and applications that can easily be used to (objectively) measure cycling. Secondly, we found that interventions evaluated in independent groups posttest only designs typically yielded larger effects than interventions evaluated in independent groups pretest-posttest designs and single group pretest-posttest designs. One interpretation is that not taking baseline scores into account may artificially inflate the differences observed between experimental groups. Therefore independent groups pretest-posttest designs should be seen as the gold standard and used to test interventions where possible (Morris & DeShon, 2002).

Sample moderators

None of the sample related factors moderated the outcomes of interventions in the present review except the nature of the target sample. Interventions targeting specific groups (e.g., university staff and students, employees of a specific company) were typically more effective than interventions targeting members of the general population. One explanation is that interventions targeting a specific target group are better tailored to the needs of their samples and / or the challenges that they face and previous reviews have found that tailored interventions tend to be more effective in changing behaviour (Bird et al., 2013; Zimmerman, Olsen, & Bosworth, 2000). The finding that age and being female did not moderate the effectiveness of interventions in the present review is encouraging as it suggests that interventions designed to promote cycling can be effective regardless of participants' age, gender, or ethnicity.

Limitations and future directions

One limitation of the existing review is that BCTs were coded simply as present or absent, which does not capture intensity or variability within BCTs. For instance, restructuring the physical environment (BCT 12.1) can be used to describe an intervention that simply repaints existing bike paths as well as an intervention that provides an entirely new traffic free bicycle path. Furthermore, many of the studies did not fully report sample characteristics, intervention components, or analyses – therefore some of the moderator analyses were based on a reduced number of studies. These differences might be due to the studies coming from various disciplines such as city and regional planning, public health, or civil engineering that differ in their approach to data collection (e.g., using aggregate level vs. individual level data), the language used to explain their interventions, and statistical methods used as well as reported in their analysis. As suggested by Colquhoun et al. (2014), developing a common methodology and terminology would help to overcome these issues.

This may also help bring multiple disciplines, such as social science, public health, and engineering, together to promote cycling.

Conclusion

The findings of the present review suggest that it is possible to promote cycling, although with the caveat that interventions typically only have a small effect. Consideration of variables that were associated with efficacy provides grounds for optimism that larger effects might be observed in the future, particularly if researchers and practitioners draw on existing evidence about what works and for whom. Our primary suggestions are that interventions seeking to increase cycling should target specific groups of people, focus on individuals rather than environments, and prompt people to self-monitor relevant behaviour. Tests of these interventions should employ independent groups pretest-posttest designs and use objective measures of behaviour. Further research is also needed to test other BCTs, or combinations of BCTs, to further increase the effectiveness of interventions, for example as highlighted by Control Theory (Carver & Scheier, 1982).

Footnotes

[1] We also tested if interventions that included a cycling course (including BCTs 4.1, 6.1, and 8.1) had larger effects than other interventions and found that interventions with a cycling course (Hedges' $g_+ = 0.10$, $k = 13$) did not have larger effects than the interventions that did not incorporate a cycling course (Hedges' $g_+ = 0.15$, $k = 35$); the results were non-significant, $Q = .45$, $p = .503$.

[2] We report ethnicity as percentage of whites in the sample because majority of the sample in each of the primary studies were white. However, we also investigated whether the percentage of each of the other ethnicities that we coded were associated with effect sizes. None of the beta weights were significant. Specifically, the percentages of Black participants ($B = 0.935$, $p = 0.293$), Asian participants ($B = 0.418$, $p = 0.134$), or Hispanic participants ($B = 0.125$, $p = 0.821$) in the sample were not associated with the effect of the interventions on cycling.

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Figure 1

Flow of Information through the Review

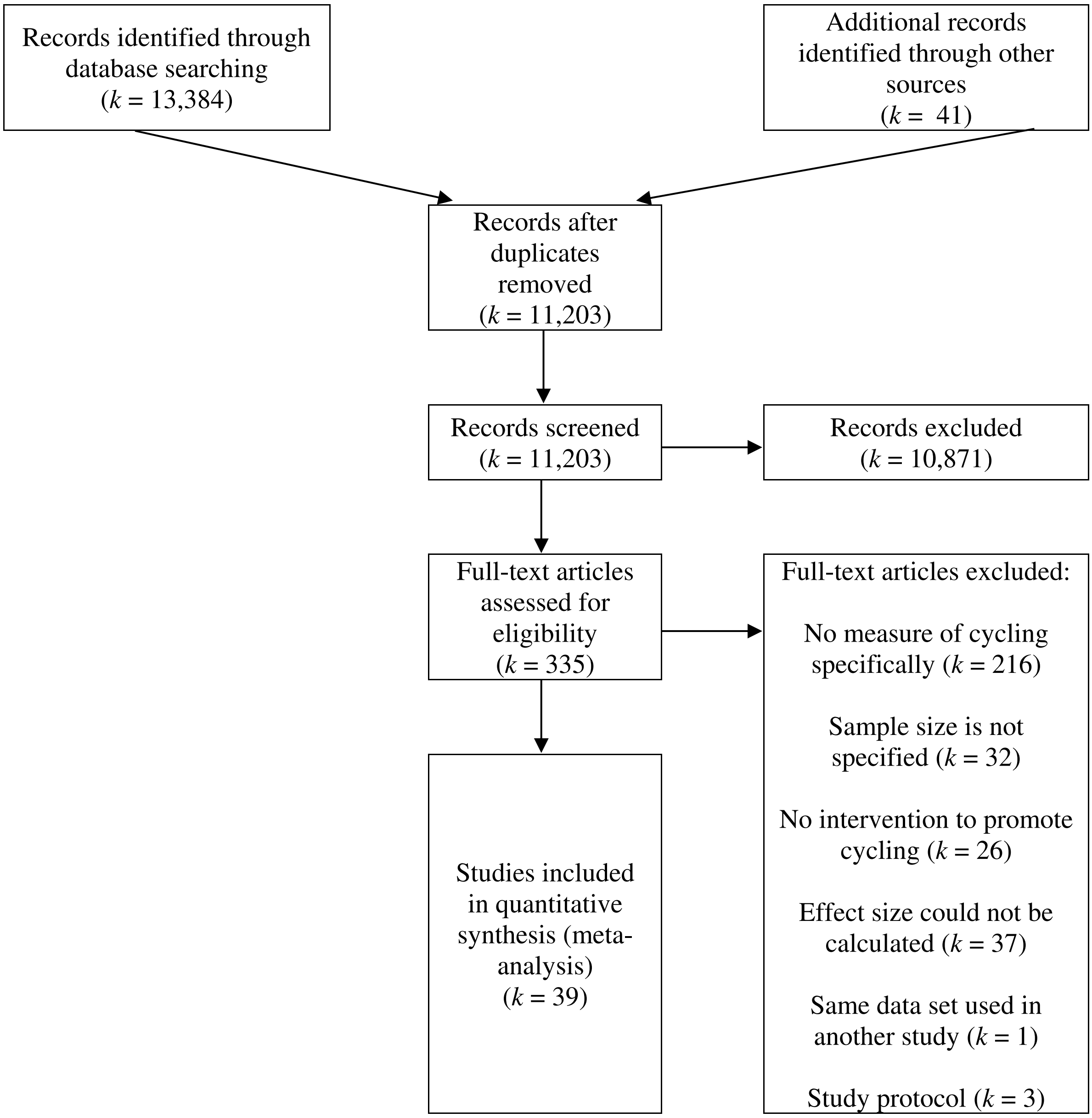

Table 1

Characteristics of the Studies Included in the Meta-Analysis

Authors (year)	Study design	Sample	Number of BCTs used in the intervention	BCTs used in the intervention [a]	Measure of cycling	N_E	N_C	*d*
Aittasalo et al. (2019)	Single group pre-post	Specific group of adults	1	12.1	Cycling frequency	402	402	0.00
Aittasalo et al. (2019)	Independent groups pre-post	Specific group of adults	1	1.4	Cycling frequency	319	124	0.12
Boarnet et al. (2013)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	103	100	0.12
Bourdeaudhuij et al. (2010) [b]	Independent groups pre-post	12-13 year-olds	0	-	Minutes cycled	581	469	0.15
Brown et al. (2016)	Independent groups pre-post	Members of general population	1	12.1	Cycling status	268	268	0.27
Burbidge & Goulias (2009)	Single group pre-post	Members of general population	1	12.1	Cycling status	98	98	-0.01
Cook et al. (2014)	Independent groups pre-post	13-15 year-olds	8	2.2, 3.1, 4.1, 4.2, 5.3, 6.2, 9.1, 12.2	Minutes cycled	278	277	0.13
	Independent groups pre-post	16-18 year-olds	8	2.2, 3.1, 4.1, 4.2, 5.3, 6.2, 9.1, 12.2	Minutes cycled	127	127	0.40
Crane et al. (2017)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	189	229	-0.24
Dill et al. (2014)	Independent groups pre-post	Members of general population	1	12.1	Minutes cycled	63	38	-0.47
	Independent groups pre-post	Members of general population	1	12.1	Number of trips	81	64	-0.09
Diniz et al. (2015)	Independent groups pre-post	Specific group of adults	4	4.1, 6.1, 8.1, 10.2	Cycling status	438	438	0.07
Dogru et al. (2018) (1 BCT vs control)	Independent groups pre-post	Specific group of adults	1	2.3	Cycling frequency	27	20	0.35
Dogru et al. (2018) (3 BCTs vs control)	Independent groups pre-post	Specific group of adults	3	1.1, 1.4, 2.3	Cycling frequency	26	20	0.53
Droomers et al. (2015) (18 neighbourhoods vs control)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	870	115	-0.41

Droomers et al. (2015) (24 neighbourhoods vs control)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	1,018	114	-0.37
Dubuy et al. (2013)	Independent groups	Specific group of adults	3	10.1, 10.2, 12.2	Cycling frequency	422	227	0.37
Ducheyne et al. (2014) (I vs CG)	Independent groups pre-post	Primary school students	3	4.1, 6.1, 8.1	Minutes cycled	12	18	-0.26
Ducheyne et al. (2014) (I+PI vs CG)	Independent groups pre-post	Primary school students	4	4.1, 6.1, 8.1, 12.2	Minutes cycled	17	17	-0.27
Ducheyne et al. (2014) (I+PI vs I)	Independent groups pre-post	Primary school students	1	12.2	Minutes cycled	17	13	-0.02
Fuller et al. (2013)	Independent groups pre-post	Members of general population	1	12.5	Cycling status	802	1590	0.58
Fyhri & Fearnley (2015)	Independent groups pre-post	Specific group of adults	2	2.3, 12.5	Cycling share	22	53	0.56
	Independent groups pre-post	Specific group of adults	2	2.3, 12.5	Distance cycled/day	22	54	0.78
	Independent groups pre-post	Specific group of adults	2	2.3, 12.5	Number of trips	22	53	0.45
Gase et al. (2015)	Independent groups	Members of general population	4	4.1, 6.1, 8.1, 12.5	Cycling frequency	304	318	0.19
Goodman et al. (2013a)	Single group pre-post	Members of general population	1	12.1	Cycling status	1,235	1,235	0.13
Goodman et al. (2013b)	Independent groups pre-post	Members of general population	6	3.1, 4.1, 6.1, 8.1, 12.1, 12.2	Cycling status	2563 (Winzorized)	2881 (Winzorized)	0.01
Goodman et al. (2016)	Independent groups	10-11 year old children	3	4.1, 6.1, 8.1	Cycling status	2563	773	-0.01
Groesz (2007)	Independent groups pre-post	Primary school children	5	3.1, 4.1, 4.2, 6.1, 8.1	Cycling status	63	38	0.09
Heinen et al. (2015)	Independent groups	Members of general population	1	12.1	Cycling status	227	226	0.46
Hemmingsson et al. (2009)	Independent groups	Specific group of adults	3	3.1, 8.2, 12.2	Cycling status	27	22	1.03
	Independent groups	Specific group of adults	3	3.1, 8.2, 12.2	Cycling status	27	23	1.06
Hosford et al. (2019)	Independent groups pre-post	Members of general population	1	12.5	Cycling status	2563 (Winzorized)	2881 (Winzorized)	0.40
Houston et al. (2015)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	104	69	0.10
Jia & Fu (2019)	Independent groups	Members of general population	1	12.5	Cycling status	289	102	0.43

Keall et al. (2015)	Independent groups pre-post	Members of general population	1	12.1	Moderate cycling minutes	123	50	-0.09
	Independent groups pre-post	Members of general population	1	12.1	Moderate cycling occurrence	122	51	0.10
	Independent groups pre-post	Members of general population	1	12.1	Vigorous cycling minutes	122	51	-0.21
	Independent groups pre-post	Members of general population	1	12.1	Vigorous cycling occurrence	123	50	0.10
Krizek et al. (2009)	Single group pre-post	Members of general population	1	12.1	Cycling status	2563 (Winzorized)	2881 (Winzorized)	0.02
Mendoza et al. (2017)	Independent groups pre-post	10-12 year-old children	5	4.1, 6.1, 8.1, 12.2, 12.5	Minutes cycled	24	30	1.83
Merom et al. (2003)	Independent groups pre-post	Members of general population	1	12.1	Minutes cycled	96	163	0.28
Moser et al. (2019)	Single group pre-post	Specific group of adults	1	10.8	Cycling status	70	70	0.54
Ostergaard et al. (2015)	Independent groups pre-post	10-11 year-old children	4	3.1, 12.1, 12.2, 12.5	Cycling status (Other than to school)	462	332	0.05
	Independent groups pre-post	10-11 year-old children	4	3.1, 12.1, 12.2, 12.5	Cycling status (Cycling to school)	461	331	0.07
Panter et al. (2016)	Single group pre-post	Members of general population	1	12.1	Minutes cycled	305	305	-0.41
Piwek et al. (2015)	Independent groups pre-post	Specific group of adults	1	2.3	Cycling frequency	5	5	0.14
	Independent groups pre-post	Specific group of adults	1	2.3	Cycling frequency	6	6	0.32
Rissel et al. (2010)	Independent groups pre-post	Members of general population	5	4.1, 5.1, 6.1, 8.1, 8.7	Cycling status	520	389	-0.01
Rissel et al. (2015)	Independent groups	Members of general population	1	12.1	Cycling status	240	272	0.08
Sersli et al. (2019)	Independent groups pre-post	Members of general population	5	4.1, 5.1, 6.1, 8.1, 8.7	Cycling frequency	135	43	0.17
Stralen et al. (2010) (EG1 vs CG)	Independent groups pre-post	Members of general population	11	1.2, 1.4, 1.6, 2.2, 3.1, 4.1, 6.2, 8.3, 9.1, 9.2, 10.4	Minutes cycled for leisure	104	114	0.01
	Independent groups	Members of general population	11	1.2, 1.4, 1.6, 2.2, 3.1, 4.1,	Minutes cycled	105	115	0.04

	pre-post			6.2, 8.3, 9.1, 9.2, 10.4	for transportation			
Stralen et al. (2010) (EG2 vs CG)	Independent groups pre-post	Members of general population	12	1.2, 1.4, 1.6, 2.2, 3.1, 4.1, 4.2, 6.2, 8.3, 9.1, 9.2, 10.4	Minutes cycled for leisure	113	115	0.13
	Independent groups pre-post	Members of general population	12	1.2, 1.4, 1.6, 2.2, 3.1, 4.1, 4.2, 6.2, 8.3, 9.1, 9.2, 10.4	Minutes cycled for transportation	112	114	0.06
Stralen et al. (2010) (EG2 vs EG1)	Independent groups pre-post	Members of general population	1	4.2	Minutes cycled for leisure	113	105	0.11
	Independent groups pre-post	Members of general population	1	4.2	Minutes cycled for transportation	112	104	0.02
Teyhan et al. (2016)	Independent groups	14 year-old children	3	4.1, 6.1, 8.1	Cycling status	2041	2881	0.19
	Independent groups	16 year-old children	3	4.1, 6.1, 8.1	Cycling status	1779	2347	0.17
Villa et al. (2016)	Independent groups pre-post	8-11 year-old children	3	4.1, 6.1, 8.1	Cycling status	117	89	0.00

Note. [a] BCT No = number of the behaviour change technique as given in the original taxonomy (Michie et al., 2013). [b] This study compared a tailored versus a non-tailored intervention.

Table 2

Sample-weighted Average Effect Sizes (ES) for Interventions Including vs. Excluding Specific BCTs

BCT No.	BCT	*k*	g_+ present (95% CI)	g_+ absent (95% CI)	Q for difference	*p*-value
1.1	Goal setting (behaviour)	1	-	-	-	-
1.2	Problem solving	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
1.4	Action planning	4	0.09 (-0.01, 0.19)	0.14 (0.05, 0.23)	0.52	0.470
1.6	Discrepancy between current behaviour and goal	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
2.2	Feedback on behaviour	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
2.3	Self-monitoring of behaviour	4	0.48 (0.36, 0.59)	0.12 (0.03, 0.21)	8.50	0.004
3.1	Social support (unspecified)	8	0.16 (-0.03, 0.34)	0.13 (0.03, 0.23)	0.13	0.718
4.1	Instruction on how to perform a behaviour	16	0.11 (0.00, 0.22)	0.15 (0.04, 0.26)	0.31	0.577
4.2	Information about antecedents	5	0.14 (0.03, 0.26)	0.14 (0.04, 0.23)	0.01	0.903
5.3	Information about social and environmental consequences	2	0.25 (-0.02, 0.52)	0.13 (0.04, 0.22)	0.66	0.415
6.1	Demonstration of the behaviour	13	0.10 (-0.03, 0.24)	0.15 (0.05, 0.25)	0.45	0.503
6.2	Social comparison	4	0.14 (-0.01, 0.29)	0.14 (0.04, 0.23)	0.01	0.939
8.1	Behavioural practice/rehearsal	13	0.10 (-0.03, 0.24)	0.15 (0.05, 0.25)	0.45	0.503
8.2	Behaviour substitution	1	-	-	-	-
8.3	Habit formation	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
8.7	Graded tasks	1	-	-	-	-
9.1	Credible source	4	0.14 (-0.01, 0.29)	0.14 (0.04, 0.23)	0.01	0.939
9.2	Pros and cons	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
10.1	Material incentive (behaviour)	1	-	-	-	-
10.2	Material reward (behaviour)	2	0.22 (-0.08, 0.52)	0.13 (0.04, 0.22)	0.29	0.591
10.4	Social reward	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
12.1	Restructuring the physical environment	18	-0.01 (-0.12, 0.10)	0.24 (0.14, 0.35)	18.16	0.000
12.2	Restructuring the social environment	10	0.27 (-0.02, 0.56)	0.11 (0.03, 0.19)	3.00	0.083
12.5	Adding objects to the environment	8	0.45 (0.15, 0.75)	0.08 (0.00, 0.15)	14.72	0.000

Note: BCT No = number of the behaviour change technique as given in the original taxonomy (Michie et al., 2013), BCT = name of the behaviour change technique

Table 3

Other Moderators of the Effect of Interventions on Cycling: Sample-weighted Average Effect Sizes (ES)

			Categorical			Continuous	
Moderators	*N*	*k*	Levels of the moderator	*Q*	*g+* [95 % CI]	*β*	SE
Sample moderators							
Age (in years)	19,190	24				-0.002	0.00
Ethnicity (percentage of whites)	12,302	15				-0.248	0.21
Gender (percentage of females)	34,110	39				0.380	0.29
Modal level of education	30,505	31		0.15			
	5,182	4	No education		0.22 [-0.41, 0.85]		
	11,102	9	Primary school		0.17 [0.14, 0.21]		
	3,203	8	High school		0.19 [0.05, 0.34]		
	11,018	10	Undergraduate or above		0.18 [0.01, 0.36]		
Type of sample	46,102	48		6.99*			
	16,284	13	Children or adolescents		0.16 [-0.03, 0.35]		
	2,880	10	Specific group of adults		0.33 [0.14, 0.52]		
	26,938	25	General population		0.07 [-0.03, 0.18]		
Methodological moderators							
Blinding (assessors)	46,102	48		2.03			
	93	2	Blind		0.43 [0.26, 0.61]		
	46,009	46	Not blind		0.13 [0.04, 0.22]		
Blinding (participants)	46,102	48		2.03			
	93	2	Blind		0.43 [0.26, 0.61]		
	46,009	46	Not blind		0.13 [0.04, 0.22]		
Intervention length	46,102	48				-0.016	0.02

Nature of the measure of cycling	46,102	48		6.72**			
	7,021	11	Objective		0.37 [0.08, 0.66]		
	39,081	37	Self-report		0.09 [0.02, 0.17]		
Outcomes measured	46,102	48		3.50			
	3,919	12	Time		0.13 [-0.12, 0.39]		
	6,362	16	Distance		0.05 [-0.10, 0.19]		
	35,821	20	Frequency		0.21 [0.10, 0.31]		
Randomization	46,102	48		2.80			
	10,620	21	Randomized		0.10 [-0.01, 0.21]		
	35,482	27	Not randomized		0.18 [0.05, 0.32]		
Rate of participation	28,229	33				-0.071	0.16
Recruitment method	46,102	48		2.30			
	404	2	Self-initiated		0.36 [0.01, 0.72]		
	1,447	4	By medical professionals		0.24 [-0.19, 0.68]		
	31,303	30	By researchers		0.10 [0.00, 0.20]		
	12,948	12	By school		0.16 [0.01, 0.32]		
Representativeness of population	44,754	45		0.01			
	15,700	15	Representative		0.15 [0.03, 0.27]		
	29,054	30	Not representative		0.14 [0.02, 0.27]		
Theory use in intervention development	46,102	48					
	4283	9	Used		0.17 [0.01, 0.33]		
	41819	39	Not used		0.13 [0.03, 0.23]		

Note: N = number of participants included this analysis, k = number of unique effect sizes measured for this analysis, CI = confidence interval, SE = standard error, BCTs = behaviour change techniques.

* $p < .05$, ** $p < .01$, *** $p < .001$