The co-benefits of active travel interventions beyond physical activity: a systematic review

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Active travel is a widely recognised strategy for promoting active living but its co-benefits beyond increasing physical activity, such as broader health, environmental, and social benefits, have rarely been synthesised. We conducted a systematic review to examine the co-benefits of active travel interventions. Following a preregistered protocol (PROSPERO CRD42022359059), we identified 80 studies for the search period from Jan 1, 2000, to Sept 13, 2022. Across studies, there was consistent evidence that active travel interventions offered co-benefits beyond physical activity. Particularly, 25 (71%) of 35 studies favoured improved safety outcomes, 20 (67%) of 30 showed improved health, 17 (85%) of 20 supported economic benefits, 16 (84%) of 19 highlighted improved transport quality, 12 (92%) of 13 showed environmental benefits, and four (80%) of five documented social benefits. Despite the overall low-certainty evidence, mostly limited by the quasi-experimental design and natural-experimental design of many of the studies, active travel interventions offer unique opportunities to engage stakeholders across sectors to jointly address major societal issues, such as physical inactivity, traffic safety, and carbon emissions. This evidence can inform the design, implementation, and evaluation of active travel interventions.

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See **Online** for appendix

Introduction

Private car use contributes substantially to carbon emissions, air pollution, and noise pollution.[1] Furthermore, car dependency fosters a spectrum of health and social issues, including congestion, road injuries and fatalities, psychological distress, and sedentary lifestyles that increase susceptibility to obesity and chronic diseases.[2] Conversely, active travel (also known as active transport or active commuting), which refers to travel behaviour involving physical activity such as walking and cycling to or from destinations, contributes to higher rates of physical activity overall,[3] and is a key focus of the WHO's Global Action Plan on Physical Activity 2018–2030.[4] Improving sustainable urban transportation is part of the UN's Sustainable Development Goals (SDGs),[5] and many governments around the world are committed to reducing transport-related carbon emissions through prioritising active transportation.

Active travel interventions have been recognised as one of eight investments that work for physical activity promotion.[6] Over the past two decades, numerous active travel intervention studies have been conducted, often in transport or public health, and typically evaluating intervention effects on travel behaviour or physical activity outcomes.[7,8] However, active travel interventions are likely to yield broader co-benefits, such as environmental (eg, carbon emissions and air pollution),[9] economic (eg, travel costs and productivity),[10] and safety (eg, traffic safety and personal safety) benefits. Capitalising on the synergy of potential co-benefits, some initiatives have been implemented to integrate the policy, research, and practice agenda across transport, health, and environmental sectors, such as the Transport, Health and Environment Pan-European Programme (THE PEP)[11] and the Physical Activity Through Sustainable Transport Approaches project.[12] However, to date, a systematic review of a broad range of co-benefits of active travel interventions has not been conducted. The few existing systematic reviews either focused on a particular type of co-benefit (eg, economic co-benefits[10]) or specific settings (eg, active travel interventions in schools[13]). The potential co-benefits of active travel interventions have not been comprehensively synthesised. Understanding of this knowledge and capitalisation on such crucial information could help drive a cross-sectoral effort towards promoting active lifestyles and addressing other major global challenges, such as climate change.[14] This systematic review aims to synthesise the evidence on the co-benefits of active travel interventions.

Methods

The protocol for this systematic review was registered with PROSPERO (CRD42022359059; appendix p 2). This systematic review follows the PRISMA[15] (appendix pp 3–6) and SWiM guidelines (appendix p 7).[16] Studies were eligible if they met all the following criteria for study design, intervention, control or comparison groups, and outcomes. There were no restrictions regarding the population.

Study design

Empirical studies with an experimental design (eg, randomised controlled trials [RCT]) or quasi-experimental design or natural-experimental design (study designs that evaluate events, whether unplanned or planned but occurring outside of the researchers' control, such as interventions, policies, and programmes specifically aimed at influencing an outcome), which divide a population into exposed and unexposed groups, or groups with different rates of exposure, were selected.[17,18] We included non-randomised designs despite them being less methodologically rigorous than RCTs as these are the most common study designs for active travel interventions.[8]

Intervention

Interventions were defined as any action that might have led to a change in active travel behaviour, regardless of whether it was the primary or intended outcome. Interventions could be directed at individuals (eg, social media and education campaigns), settings (eg, school and workplace-based programmes), built environment (eg, bicycle paths and parks), or policies (eg, taxation, subsidies, and mandates). Active travel was defined as any physically active travel behaviour (ie, getting from place to place) and not solely for recreation or fitness. Therefore, interventions focusing on overall activity, not transport-specific physical activity, were excluded. Although active travel literature traditionally focuses on walking and cycling, more inclusive definitions have been proposed,[19] and some studies suggest that public transport be included because it offers opportunities for physical activity.[20] We did not limit the specific type of behaviour in the definition of active travel if it involved physical activity.

Control or comparison group

Included a no intervention, attention control, or minimal intervention control or comparison group, area, timepoint, or population, or controlled comparisons (eg, variation in exposure as the basis for comparisons).

Outcomes

Outcomes included at least one physical activity (eg, changes in walking or cycling or total physical activity), which was considered the main benefit, and at least one non-physical activity outcome, which we treated as a potential co-benefit of the intervention. We excluded post-intervention only, modelling (simulation) studies (unless used to evaluate real-life interventions), and studies without a true standard control group as a comparator. Specifically, we excluded studies where the control consisted of an alternative intervention that was intended or likely to promote active travel, or an alternative intervention that was reasonably considered to exceed standard care, treatment, or practice. We considered academic and grey literature in any language if they had an English title, abstract, or summary.

Search strategy and selection criteria

Systematic searches were conducted to locate relevant studies published from Jan 1, 2000, to Sept 13, 2022. This search period was considered appropriate as studies examining relationships between promotion strategies for physical activity and co-benefits have mainly emerged in the past decade.[21] Searches for articles published in peer-reviewed journals and grey literature were conducted in five electronic databases: Web of Science, PsycINFO, PubMed, Cochrane, and Transport Research International Documentation. These databases were selected to cover a broad range of disciplines and were the most common databases used in previous reviews of active travel, walking, or cycling interventions.[7,22–24] Our search strategies in all five databases included a combination of active travel and intervention search terms (appendix pp 8–11).

Systematic searches were supplemented by searching reference lists of relevant papers (appendix p 12), including several selected key reviews of active travel and physical activity,[7,23–26] and any active travel review published from Jan 1, 2000, to Sept 13, 2022, identified by our database searches or by nominated experts from the authors' professional network.

All search results were imported into Covidence software, where titles and abstracts were screened by one of two authors (BN or TN) to identify studies that potentially met the inclusion criteria. Pairs of authors (BN, DD, ML, or TN) then screened the full-text articles independently (agreement 99·88%) and any disagreements were resolved by a third reviewer.

Data extraction

A standardised, pre-piloted form was used to extract data from the included studies. Extracted information included: study name, country, study design, setting and population, type of active travel intervention, final sample size in the intervention population, domain of co-benefit studied, follow-up period for measurement of the co-benefit, number of co-benefit outcomes, and reported effects for co-benefits. All fields were extracted in duplicate for each study by two of several authors (BN, ML, or TN) working independently, except for country, setting, study design, study population, and follow-up period for measurement of co-benefits, which were extracted by one review author (BN or ML).

The non-mutually exclusive categories used to classify types of active travel interventions were mainly based on those used in two previous reviews[7,23] and included: mass media, social media, education or behaviour-change strategies, city-wide and town-wide environmental changes, building or improving local routes or networks, school and workplace approaches, policies with direct restrictions and mandates, financial measures, and others (eg, bicycle-sharing systems). Co-benefits were defined as any outcome of interest besides physical activity (ie, primary benefits) and classified into the following outcome domains, informed by and expanding upon an established co-benefits classification method:[27] safety (eg, traffic safety), health (eg, mental health and wellbeing), economic (eg, productivity), transport quality (eg, quality of service), environment (eg, greenhouse gas emissions and air pollution), and social benefits (eg, social connectedness).

Risk of bias

Two authors (BN, MFPI, or ML) independently appraised the quality of included studies, with an adapted version of the binary criteria used in systematic reviews led by Ogilvie and colleagues[26] and Foster and collagues,[7] which are applicable across the range of included study designs.

Such an approach is considered more appropriate for reviews that include different study designs than using assessment criteria specific to one study type.[28] The following five binary criteria were used: randomisation (participating individuals, groups, or areas were randomly allocated to intervention and control status); exposure (participants did not receive a concurrent intervention that could have differentially influenced active travel behaviour in the intervention and control groups, and the control group was not contaminated by receiving part or all of the intervention being studied); representativeness (samples were randomly recruited from the study population with a response rate of at least 60%, or were otherwise shown to be representative of the study population); comparability (baseline characteristics of the intervention and control groups, populations, or areas were comparable, or if there were important differences at baseline, these characteristics were appropriately adjusted for in the analysis); and attrition or sample size (outcomes studied in a sample of respondents had an attrition rate of less than 30%, or for studies using repeated cross-sectional design for evaluating interventions, the minimum achieved sample size was at least 100 participants in each wave in both intervention and control groups). Disagreements between the authors over the quality assessment of specific studies were resolved by discussion, with the involvement of a third review author where necessary.

Data synthesis and analysis

Characteristics of the selected studies were tabulated according to country or geographical region (eg, North America), setting (eg, built environment, school, or workplace), study design (ie, RCT, cluster RCT, quasi-experiment, or natural experiment), intervention type (eg, building or improving local routes or networks, school and workplace programmes, or financial measures), and co-benefit outcome domain (eg, safety or health). The grouping for categorising intervention types was adapted from previous reviews,[7,23] the settings from the Eight Investments that Work for Physical Activity[6] and the co-benefit outcome domains from Sallis and colleagues.[27] In cases where studies reported equity outcomes (eg, the extent to which different socioeconomic subgroups benefited from the intervention), we considered them in their relevant outcome domain. For example, if a study examined whether the intervention effects on health differed by socioeconomic subgroups, we classified these outcomes under health, and if a study examined whether the intervention effects on transport access differed by socioeconomic subgroups, we classified these outcomes under transport quality.

Findings from the included studies, organised by the type of active travel intervention and outcome domains, were summarised using a narrative synthesis and an effect direction plot. The effect direction plot is a valid method for combining and presenting findings on outcome domains for outcomes that are conceptually similar but measured by studies in different ways. This approach does not rely on the statistical significance of outcomes.[29] There was limited scope for meta-analysis due to heterogeneity in study designs, types of interventions, participants, and co-benefit outcome metrics.

We used vote counting to investigate whether active travel interventions have been found to have any effect on the co-benefit outcomes of interest. Studies were classified according to whether they favoured the intervention, showed no change or mixed effects, or did not favour the intervention for each co-benefit outcome assessed. Statistical significance was not considered for assessing the direction of the effect as per recommendations by Boon and Thomson.[29] Where a study reported multiple outcomes belonging to the same co-benefit domain, we determined the overall effect direction for that domain according to the following criteria stated by Boon and Thomson:[29] (1) if multiple outcomes belonging to the same outcome domain reported the same effect direction, that effect direction was reported; and (2), if multiple outcomes within an outcome domain reported different effect directions where 70% or more of outcomes reported a similar direction, this effect direction was reported. Where less than 70% of outcomes reported the same direction of effect, no clear effects (or mixed

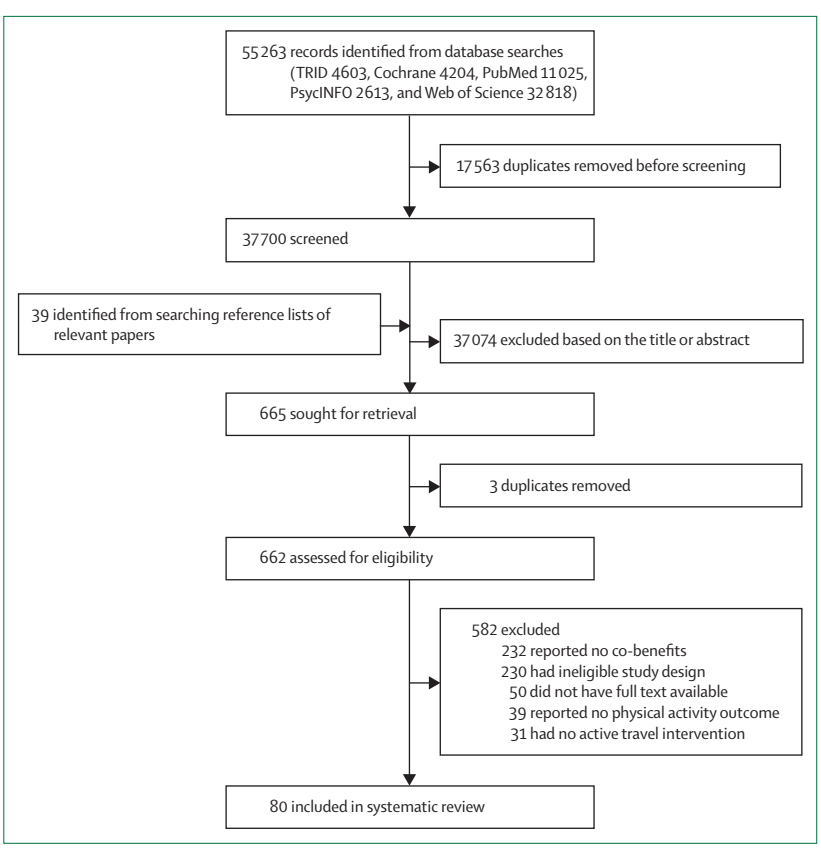


Figure 1: **Study selection**
TRID=Transport Research International Documentation.

	Number of studies (%)	Reference
Country or geographical region		
North America	32 (40%)	Anderson et al (2021),[32] Arancibia et al (2019),[33] Boarnet et al (2005),[34] Brown et al (2016),[10] Bungum et al (2014),[35] Buttazzoni et al (2019),[36] Clockston and Rojas-Rueda (2021),[37] DiMaggio et al (2014),[38] DiMaggio et al (2015),[39] DiMaggio et al (2016),[40] Frank et al (2021),[41] Freemark et al (2022),[42] Fuller et al (2013),[43] Goodno et al (2013),[44] Gutierrez et al (2008),[45] Heelan et al (2009),[46] Hou et al (2020),[47] Kang et al (2020),[48] Kong et al (2010),[49] Mackey et al (2019),[50] Mendoza et al (2012),[51] Orenstein et al (2007),[52] Page and Nilsson (2017),[53] Parks et al (2012),[54] Pedroso et al (2016),[55] Pérez et al (2017),[56] Quarles (2012),[57] Ryan (2016),[58] Soto et al (2021),[59] van Lierop et al (2016),[60] Wali et al (2022),[61] Xu (2019)[62]
UK	17 (21%)	Aldred et al (2019),[63] Aldred et al (2019),[64] Aldred et al (2021),[65] Audrey et al (2015),[66] Audrey et al (2019),[67] Brand et al (2014),[68] Goodman et al (2013),[69] Le Gouais et al (2021),[70] Li et al (2018),[71] Martin et al (2021),[72] Mutrie et al (2002),[73] Rowland et al (2003),[74] Sahlqvist et al (2015),[75] Sloman et al (2009),[76] Sloman et al (2010),[77] Sustrans (2014),[78] Wall et al (2017)[79]
Other European countries	19 (24%)	Aittasalo et al (2019),[80] Børrestad et al (2012),[81] Brey et al (2017),[82] Cambra and Moura (2020),[83] Christiansen et al (2014),[84] Ek et al (2020),[85] Fyhri et al (2016),[86] Fyhri et al (2020),[87] Fyhri et al (2020),[88] Marqués et al (2015),[89] Mrkajic et al (2015),[90] Østergaard et al (2015),[91] Otero et al (2018),[92] Pérez et al (2017),[93] Pérez-Martin et al (2018),[94] Plasencia-Lozano (2021),[95] Sareban et al (2020),[96] Troelsen (2005),[97] Villa-González et al (2017)[98]
Australia or New Zealand	9 (11%)	Australian Greenhouse Office (2005),[99] Chapman et al (2018),[100] Crane et al (2017),[101] Harris et al (2014),[102] Keall et al (2018),[103] Keall et al (2022),[104] Koorey et al (2016),[105] Rissel et al (2015),[106] Smith et al (2020)[107]
Asia	3 (4%)	He et al (2021),[108] Said et al (2020),[109] Zhou et al (2020)[110]
Setting*		
Built environment	45 (56%)	Aldred et al (2019),[63] Aldred et al (2019),[64] Aldred et al (2021),[65] Anderson et al (2021),[32] Arancibia et al (2019),[33] Australian Greenhouse Office (2005),[99] Brand et al (2014),[68] Brey et al (2017),[82] Brown et al (2016),[10] Cambra and Moura (2020),[83] Chapman et al (2018),[100] Crane et al (2017),[101] Frank et al (2021),[41] Freemark et al (2022),[42] Fyhri et al (2020),[87] Fyhri et al (2020),[88] Goodman et al (2013),[69] Goodno et al (2013),[44] Harris et al (2014),[102] He et al (2021),[108] Keall et al (2018),[103] Keall et al (2022),[104] Koorey et al (2016),[105] Le Gouais et al (2021),[70] Li et al (2018),[71] Marqués et al (2015),[89] Martin et al (2021),[72] Orenstein et al (2007),[52] Østergaard et al (2015),[91] Parks et al (2012),[54] Pedroso et al (2016),[55] Pérez et al (2017),[93] Pérez et al (2017),[56] Plasencia-Lozano (2021),[95] Rissel et al (2015),[106] Sahlqvist et al (2015),[75] Said et al (2020),[109] Sloman et al (2009),[76] Sloman et al (2010),[77] Smith et al (2020),[107] Sustrans (2014),[78] Troelsen (2005),[97] Wali et al (2022),[61] Wall et al (2017),[79] Zhou et al (2020)[110]
School	25 (31%)	Australian Greenhouse Office (2005),[99] Boarnet et al (2005),[34] Børrestad et al (2012),[81] Bungum et al (2014),[35] Buttazzoni et al (2019)[36] Christiansen et al (2014),[84] DiMaggio et al (2014),[38] DiMaggio et al (2015),[39] DiMaggio et al (2016),[40] Gutierrez et al (2008),[45] Heelan et al (2009),[46] Kang et al (2020),[48] Kong et al (2010),[49] Mendoza et al (2012),[51] Mrkajic et al (2015),[90] Orenstein et al (2007),[52] Østergaard et al (2015),[91] Pérez-Martin et al (2018),[94] Quarles (2012),[57] Rowland et al (2003),[74] Sloman et al (2009),[76] Sloman et al (2010),[77] Smith et al (2020),[107] van Lierop et al (2016),[60] Villa-González et al (2017)[98]
Workplace	12 (15%)	Aittasalo et al (2019),[80] Audrey et al (2015),[66] Audrey et al (2019),[67] Australian Greenhouse Office (2005),[99] Harris et al (2014),[102] Mutrie et al (2002),[73] Page and Nilsson (2017),[53] Pérez et al (2017),[56] Sareban et al (2020),[96] Sloman et al (2009),[76] Sloman et al (2010),[77] Wall et al (2017)[79]
Bicycle-sharing systems and programmes	7 (9%)	Clockston and Rojas-Rueda (2021),[37] Fuller et al (2013),[43] Hou et al (2020),[47] Otero et al (2018),[92] Ryan (2016),[58] Soto et al (2021),[59] Xu (2019)[62]
Other	4 (5%)	Ek et al (2020),[85] Fyhri et al (2016),[86] Mackey et al (2019),[50] Wall et al (2017)[79]
Study design		
Quasi-experiment and natural experiment	70 (88%)	Aittasalo et al (2019),[80] Aldred et al (2019),[63] Aldred et al (2019),[64] Aldred et al (2021)[65] Anderson et al (2021),[32] Arancibia et al (2019),[33] Australian Greenhouse Office (2005),[99] Boarnet et al (2005),[34] Brand et al (2014),[68] Brey et al (2017),[82] Brown et al (2016),[10] Bungum et al (2014),[35] Buttazzoni et al (2019),[36] Cambra and Moura (2020),[83] Chapman et al (2018),[100] Clockston and Rojas-Rueda (2021),[37] Crane et al (2017),[101] DiMaggio et al (2014),[38] DiMaggio et al (2015),[39] DiMaggio et al (2016),[40] Frank et al (2021),[41] Freemark et al (2022),[42] Fuller et al (2013),[43] Fyhri et al (2016),[86] Fyhri et al (2020),[87] Fyhri et al (2020),[88] Goodno et al (2013),[44] Goodman et al (2013),[69] Gutierrez et al (2008),[45] Harris et al (2014),[102] He et al (2021),[108] Heelan et al (2009),[46] Hou et al (2020),[47] Kang et al (2020),[48] Keall et al (2018),[103] Keall et al (2022),[104] Kong et al (2010),[49] Koorey et al (2016),[105] Le Gouais et al (2021),[70] Li et al (2018),[71] Marqués et al (2015),[89] Martin et al (2021),[72] Mrkajic et al (2015),[90] Orenstein et al (2007),[52] Østergaard et al (2015),[91] Otero et al (2018),[92] Page and Nilsson (2017),[53] Parks et al (2012),[54] Pedroso et al (2016),[55] Pérez et al (2017),[93] Pérez et al (2017),[56] Pérez-Martin et al (2018),[94] Plasencia-Lozano (2021),[95] Quarles (2012),[57] Rissel et al (2015),[106] Ryan (2016),[58] Said et al (2020),[109] Sahlqvist et al (2015),[75] Sloman et al (2009),[76] Sloman et al (2010),[77] Smith et al (2020),[107] Soto et al (2021),[59] Sustrans (2014),[78] Troelsen (2005),[97] van Lierop et al (2016),[60] Villa-González et al (2017),[98] Wall et al (2017),[79] Wali et al (2022),[61] Xu (2019),[62] Zhou et al (2020)[110]
Randomised controlled trial	10 (13%)	Audrey et al (2015),[66] Audrey et al (2019),[67] Børrestad et al (2012),[81] Christiansen et al (2014),[84] Ek et al (2020),[85] Mackey et al (2019),[50] Mendoza et al (2012),[51] Mutrie et al (2002),[73] Rowland et al (2003),[74] Sareban et al (2020)[96]
Intervention type*		
Building or improving local routes or networks	43 (54%)	Aldred et al (2019),[63] Aldred et al (2019),[64] Aldred et al (2021),[65] Anderson et al (2021),[32] Arancibia et al (2019),[33] Boarnet et al (2005),[34] Brand et al (2014),[68] Brey et al (2017),[82] Brown et al (2016),[10] Cambra and Moura (2020),[83] Crane et al (2017),[101] DiMaggio et al (2014),[38] DiMaggio et al (2015),[39] DiMaggio et al (2016),[40] Frank et al (2021),[41] Freemark et al (2022),[42] Fyhri et al (2020),[87] Fyhri et al (2020),[88] Goodno et al (2013),[44] Gutierrez et al (2008),[45] Harris et al (2014),[102] He et al (2021),[108] Keall et al (2018),[103] Keall et al (2022),[104] Koorey et al (2016),[105] Le Gouais et al (2021),[70] Li et al (2018),[71] Marqués et al (2015),[89] Martin et al (2021),[72] Mrkajic et al (2015),[90] Orenstein et al (2007),[52] Østergaard et al (2015),[91] Parks et al (2012),[54] Pérez et al (2017),[56] Rissel et al (2015),[106] Sahlqvist et al (2015),[75] Said et al (2020),[109] Sloman et al (2009),[76] Smith et al (2020),[107] Sustrans (2014),[78] Troelsen (2005),[97] Wali et al (2022),[61] Zhou et al (2020)[110]

(Table 1 continues on next page)

	Number of studies (%)	Reference
(Contiued from previous page)		
School and workplace approaches	32 (40%)	Aittasalo et al (2019),[80] Audrey et al (2015),[66] Audrey et al (2019),[67] Australian Greenhouse Office (2005),[99] Børrestad et al (2012),[81] Bungum et al (2014),[35] Buttazzoni et al (2019),[36] Christiansen et al (2014),[84] DiMaggio et al (2015),[39] DiMaggio et al (2016),[40] Goodman et al (2013),[69] Gutierrez et al (2008),[45] Harris et al (2014),[102] Heelan et al (2009),[46] Kang et al (2020),[48] Kong et al (2010),[49] Mendoza et al (2012),[51] Mutrie et al (2002),[73] Orenstein et al (2007),[52] Østergaard et al (2015),[91] Page and Nilsson (2017),[53] Pérez et al (2017),[93] Perez-Martin et al (2018),[94] Quarles (2012),[57] Rowland et al (2003),[74] Sloman et al (2009),[76] Sloman et al (2010),[77] Smith et al (2020),[107] Troelsen (2005),[97] van Lierop et al (2016),[60] Villa-González et al (2017),[98] Wall et al (2017)[79]
Mass media, social media, and education or behaviour-change strategies	26 (33%)	Aittasalo et al (2019),[80] Audrey et al (2015),[66] Audrey et al (2019),[67] Australian Greenhouse Office (2005),[99] Børrestad et al (2012),[81] Bungum et al (2014),[35] Chapman et al (2018),[100] DiMaggio et al (2015),[39] DiMaggio et al (2016),[40] Ek et al (2020),[85] Freemark et al (2022),[42] Goodman et al (2013),[69] Keall et al (2018),[103] Keall et al (2022),[104] Mackey et al (2019),[50] Mendoza et al (2012),[51] Mutrie et al (2002),[73] Page and Nilsson (2017),[53] Pérez-Martin et al (2018),[94] Rowland et al (2003),[74] Sareban et al (2020),[96] Sloman et al (2010),[77] Troelsen (2005),[97] van Lierop et al (2016),[60] Villa-González et al (2017),[98] Wall et al (2017)[79]
City-wide and town-wide environmental changes	8 (10%)	Aittasalo et al (2019),[80] Chapman et al (2018),[100] Goodman et al (2013),[69] Koorey et al (2016),[105] Marqués et al (2015),[89] Pedroso et al (2016),[55] Pérez et al (2017),[56] Plasencia-Lozano (2021)[95]
Bicycle-sharing systems and programmes	7 (9%)	Clockston and Rojas-Rueda (2021),[37] Fuller et al (2013),[43] Hou et al (2020),[47] Otero et al (2018),[92] Ryan (2016),[58] Soto et al (2021),[59] Xu (2019)[62]
Policies with direct restrictions and mandates	4 (5%)	Brey et al (2017),[82] Østergaard et al (2015),[91] Pérez et al (2017),[56] Plasencia-Lozano (2021)[95]
Financial measures	4 (5%)	Fyhri et al (2016),[86] Goodman et al (2013),[69] Mackey et al (2019),[50] Wall et al (2017)[79]
Co-benefits outcome domain*		
Traffic and personal safety	35 (44%)	Aittasalo et al (2019),[80] Aldred et al (2019),[63] Aldred et al (2019),[64] Boarnet et al (2005),[34] Bungum et al (2014),[35] Buttazzoni et al (2019),[36] Christiansen et al (2014),[84] DiMaggio et al (2014),[38] DiMaggio et al (2015),[39] DiMaggio et al (2016),[40] Fuller et al (2013),[43] Fyhri et al (2020),[87] Fyhri et al (2020),[88] Goodno et al (2013),[44] Gutierrez et al (2008),[45] Harris et al (2014),[102] Hou et al (2020),[47] Kang et al (2020),[48] Koorey et al (2016),[105] Marqués et al (2015),[89] Mendoza et al (2012),[51] Orenstein et al (2007),[52] Parks et al (2012),[54] Pedroso et al (2016),[55] Pérez et al (2017),[56] Pérez-Martin et al (2018),[94] Plasencia-Lozano (2021),[95] Rowland et al (2003),[74] Sahlqvist et al (2015),[75] Sloman et al (2009),[76] Sloman et al (2010),[77] Smith et al (2020),[107] Troelsen (2005),[97] van Lierop et al (2016),[60] Zhou et al (2020)[110]
Physical and mental health	30 (38%)	Aldred et al (2021),[65] Audrey et al (2019),[67] Børrestad et al (2012),[81] Brown et al (2016),[10] Chapman et al (2018),[100] Clockston and Rojas-Rueda (2021),[37] Crane et al (2017),[101] Ek et al (2020),[85] Frank et al (2021),[41] Goodman et al (2013),[69] Harris et al (2014),[102] He et al (2021),[108] Heelan et al (2009),[46] Hou et al (2020),[47] Keall et al (2022),[104] Kong et al (2010),[49] Mackey et al (2019),[50] Marqués et al (2015),[89] Martin et al (2021),[72] Mutrie et al (2002),[73] Østergaard et al (2015),[91] Otero et al (2018),[92] Page and Nilsson (2017),[53] Pérez et al (2017),[56] Quarles (2012),[57] Sareban et al (2020),[96] Sustrans (2014),[78] Troelsen (2005),[97] Villa-González et al (2017),[98] Xu (2019)[62]
Economic	20 (25%)	Aldred et al (2019),[64] Aldred et al (2021),[65] Anderson et al (2021),[32] Arancibia et al (2019),[33] Audrey et al (2015),[66] Audrey et al (2019),[67] Brey et al (2017),[82] Chapman et al (2018),[100] Clockston and Rojas-Rueda (2021),[37] Harris et al (2014),[102] Le Gouais et al (2021),[70] Marqués et al (2015),[89] Otero et al (2018),[92] Pérez et al (2017),[93] Pérez-Martin et al (2018),[94] Said et al (2020),[109] Sloman et al (2009),[76] Sustrans (2014),[78] Troelsen (2005),[97] Wali et al (2022)[61]
Transport quality	19 (24%)	Aittasalo et al (2019),[80] Aldred et al (2019),[63] Aldred et al (2019),[64] Buttazzoni et al (2019),[36] Cambra and Moura (2020),[83] Crane et al (2017),[101] Freemark et al (2022),[42] Fyhri et al (2020),[87] Fyhri et al (2020),[88] Goodno et al (2013),[44] Le Gouais et al (2021),[70] Li et al (2018),[71] Parks et al (2012),[54] Pérez et al (2017),[56] Rissel et al (2015),[106] Ryan (2016),[58] Sahlqvist et al (2015),[75] Soto et al (2021),[59] Zhou et al (2020)[110]
Environmental	13 (16%)	Aldred et al (2019),[63] Aldred et al (2019),[64] Australian Greenhouse Office (2005),[99] Brand et al (2014),[68] Chapman et al (2018),[100] Fyhri et al (2016),[86] Hou et al (2020),[47] Keall et al (2018),[103] Marqués et al (2015),[89] Mrkajic et al (2015),[90] Sloman et al (2010),[77] Sustrans (2014),[78] Wall et al (2017)[79]
Social	5 (6%)	Crane et al (2017),[101] Page and Nilsson (2017),[53] Pérez-Martin et al (2018),[94] Rissel et al (2015),[106] Smith et al (2020)[107]

*Categories are not mutually exclusive of each other; therefore, paper numbers do not all equal to 80 (100%).

Table 1: **Overall characteristics of included studies**

findings) were reported. We did not perform the sign test as the underlying assumptions for the test were not regarded as being met.[30]

The effect direction plot presents the number of studies showing a favourable, not favourable, or mixed or no-change intervention effect for each co-benefit outcome. Studies in this plot have been grouped by setting (eg, built environment, school, or workplace) and then colour-coded according to intervention type (eg, multiple interventions, environment, and settings-based). These groupings were chosen to help contextualise the results from the plot, as differences in setting and intervention type were considered relevant for exploring heterogeneity in the consistency of findings.

We used visual representation for the effect direction of a given study and outcome domain, using symbols to indicate favourable co-benefit, not favourable co-benefit, or no effect or mixed-change effects. Arrow size was chosen according to the sample size in the intervention group for a given study and outcome domain, with a large arrow indicating a sample size of more than 300, a medium arrow indicating a sample size of 50–300, and a small arrow indicating sample size of less than 50. If a sample size for the intervention group was not

reported, we selected the medium-sized arrow, unless an assumption could be made that the sample size was large (eg, based on a large population). If more than one outcome contributed to an outcome domain in a study, the number of outcomes were shown after the effect direction arrow. Where applicable, we conducted subgroup analysis by study attributes and study quality to investigate heterogeneity in findings.

Certainty assessment

We assessed the certainty of evidence using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach by outcome groups from available guidance for applying GRADE in narrative syntheses.[31] Domains including the risk of bias, indirectness, imprecision, inconsistency, and the likelihood of publication bias were rated.

Results

Initial searches across five databases yielded 55 263 total records, of which 37 700 were unique and screened (figure 1). An additional 39 records were identified from searching the reference lists of relevant papers. After excluding 37 074 records based on title or abstract, full texts of the remaining 662 were retrieved and assessed. Based on full-text assessment, 582 studies were excluded. The most common reasons for exclusion were no reporting of co-benefits outcomes (n=232) and ineligible study design (n=230), followed by unavailable full text (n=50), no reporting of physical activity outcomes (n=39), and no active travel intervention (n=31). We have listed the excluded studies and the reasons for their exclusion in the appendix (pp 13–50). A total of 80 studies were included in the systematic review (appendix pp 51–54). The overall characteristics of the studies included in this review are presented in table 1.

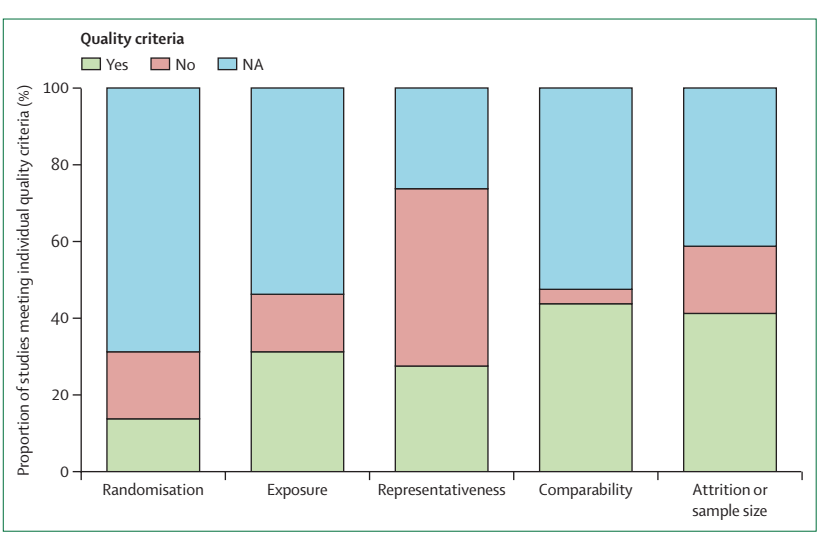


Figure 2: **Proportion of studies meeting individual quality criteria**
NA=not applicable.

Characteristics of each included study are summarised in the appendix (pp 55–64), along with their sources of funding (pp 65–67).

Of the 80 studies, most were conducted in North America (n=32; 40%), the UK (n=17; 21%), Europe (n=19; 24%), and the remaining were in Australia, New Zealand, and Asia (n=12 combined; 15%). More than half of the studies were conducted in the built environment context (n=46; 58%), nearly a third within the school context (n=25; 31%), and the rest within the context of the workplace (n=12; 15%) and bicycle-sharing programmes (n=7; 9%). Most of the studies were quasi-experiments or natural experiments (n=70; 88%), with the rest being RCTs or cluster RCTs (n=10; 13%). The most common intervention strategy was building or improving local routes or networks (n=43; 54%), followed by school and workplace programmes (n=32; 40%), mass media, social media, education, and behaviour-change strategies (n=26; 33%), city-wide and town-wide environmental changes (n=8; 10%), bicycle-sharing programmes (n=7; 9%), policies with direct restrictions and mandates (n=4; 5%), and financial measures (n=4; 5%). The intervention types were not mutually exclusive as some studies used multiple strategies (eg, a combination of education and behaviour change strategies and improvements to the built environment).[42,97,100]

13 (16%) of 80 studies met at least four of five criteria for risk of bias assessment, 11 (14%) met three, another 11 (14%) met two, 17 (21%) met one, and 28 (35%) met none. The most frequently met criteria were comparability (n=35; 44%) and attrition or sample size (n=33; 41%). The least frequently met criteria was randomisation (n=11; 14%). A full risk of bias assessment for each study is presented in the appendix (pp 68–75; figure 2)

We summarised the direction of the effect of active travel interventions across different co-benefit outcomes (figure 3) and categorised co-benefits into domains based on broad similarities in outcome measures guided by Sallis and colleagues[27] (appendix pp 76–99). Of the 80 studies, the majority (n=50; 63%) only reported on one co-benefit, whereas the rest reported on two to four co-benefits (n=30; 38%). The most examined co-benefit was safety (n=35; 44%), followed by health (n=30; 38%), and economic outcomes (n=20; 25%). The least commonly assessed co-benefit was social outcomes (n=5; 6%).

The distribution of the evidence according to whether the studies favoured the intervention for different co-benefit domains is shown in figure 4. In the following section, we summarise the co-benefits of active travel interventions according to each domain.

We considered traffic and personal safety as distinct outcomes under the broader safety domain. However, the literature was largely driven by research on traffic safety. 35 studies examined traffic safety as an outcome of active travel interventions. Traffic safety was measured objectively (eg, motor traffic volume,[64] traffic accidents,

	Summary of co-benefit findings (sample size;* direction of effect;† number of outcomes‡)					
	Safety§	Health¶	Economic	Transport quality	Environmental‖	Social**
Built environment						
Brey et al (2017)[82]			L;▲;6			
Chapman et al (2018)[100]		M;▲;2	M;▲		M;▲	
Freemark et al (2022)[42]				L;◀▶;2		
Goodman et al (2013)[69]		L;▲;4				
Keall et al (2018)[103]					L;▲	
Keall et al (2022)[104]		L;▲;2				
Plasencia-Lozano(2021)[95]	M;▲;2					
Troelsen et al (2004)[97]	L;▲;2	L;▲	L;▲;2			
Aldred et al (2019)[63]§	L;◀▶;6			L;▲;7	L;▼	
Aldred et al (2019)[64]¶	M;▲		M;▲	M;▲;5	M;▲;2	
Aldred et al (2021)[65]		L;▲;2	L;▲			
Anderson et al (2021)[32]			M;▲;5			
Arancibia et al (2019)[33]			L;▲;4			
Brand et al (2014)[68]					L;▲	
Brown et al (2016)[10]		L;◀▶				
Cambra and Moura (2020)[83]				L;▲		
Crane et al (2017)[101]		M;◀▶;2		M;▲		M;▲;2
Frank et al (2021)[41]		M;◀▶;5				
Fyhri et al (2020)[87]§	M;▲;4			M;▲;12		
Fyhri et al (2020)[88]¶	M;◀▶;3			M;◀▶;11		
Goodno et al (2013)[44]	L;▼;5			L;▲;2		
He et al (2021)[108]		L;▲;3				
Koorey et al (2016)[105]	M;▲					
Le Gouais et al (2021)[70]			L;▲	L;◀▶;5		
Li et al (2018)[71]				L;▲;3		
Marques et al (2015)[89]	L;▲;2	L;▲	L;▲		L;▲	
Martin et al (2021)[72]		L;▲;4				
Parks et al (2012)[54]	M;◀▶;2			M;▲;3		
Pedroso et al (2016)[55]	L;◀▶					
Perez et al (2017)[93]¶				L;▲;2		
Rissel et al (2015)[106]				L;▲;2		L;▼
Sahlqvist et al (2015)[75]	L;▲;3			L;▲;4		
Said et al (2020)[109]			S;▲			
Sustrans (2014)[78]		L;▲	L;▲;2		L;▲	
Wali et al (2022)[61]			M;▼			
Zhou et al (2020)[110]	L;▲;4			L;▲;2		
School						
Børrestad et al (2012)[81]††		S;◀▶;4				
Mendoza et al (2012)[51]††	M;▲;6					
Rowland et al (2003)[74]††	L;▲					
Bungum et al (2014)[35]	M;▼					
DiMaggio et al (2015)[39]	L;▲;4					
DiMaggio et al (2016)[40]	L;▲;3					
Perez-Martin et al (2018)[94]	M;▲		M;◀▶			M;▲
van Lierop et al (2016)[60]	M;▲;4					
Villa-Gonzalez et al (2017)[98]		M;◀▶;3				
Gutierrez et al (2008)[45]	L;▲					
Boarnet et al (2005)[34]	L;◀▶;2					
DiMaggio et al (2014)[37]	M;▲;2					
Mrkajic et al (2015)[90]					S;▲	
Christiansen et al (2014)[84]††	L;▼					
Buttazzoni et al (2019)[36]	L;▲;6			L;▲;2		
Heelan et al (2009)[46]		M;▲;5				
Kang et al (2020)[48]	M;▼;2					
Kong et al (2010)[49]		S;◀▶;3				
Quarles (2012)[57]		L;▲;2				
Workplace						
Audrey et al (2015)[66]††			M;◀▶;3			
Audrey et al (2019)[67]††		M;▲	M;▲;4			
Mutrie et al (2002)[73]††		M;▲;8				
Aittasalo et al (2019)[80]	M;▲;2			M;▲;3		
Page and Nillson (2017)[53]		S;▲;3				S;▲
Sareban et al (2020)[96]††		S;◀▶;5				
Built environment with school or workplace						
Australian Greenhouse Office (2005)[99]					M;▲;3	
Harris et al (2014)[64]	M;▲;2	M;▲	M;▲			
Orenstein et al (2007)[52]	L;▲;4					
Østergaard et al (2015)[91]		L;◀▶;3				
Perez et al (2017)[93]§	L;▲;4	L;▲;4	L;▲;2			
Sloman et al (2009)[76]	L;▲		L;▲			
Sloman et al (2010)[77]	L;▲				L;▲	
Smith et al (2020)[107]	M;▲;6					M;▲;2
Wall et al (2017)[79]					L;▲;2	
Other						
Mackey et al (2019)[50]††		S;◀▶;3				
Ek et al (2020)[85]††		M;▼				
Clockston and Rojas-Rueda (2021)[37]		L;▲;2	L;▲			
Fuller et al (2013)[43]	L;◀▶;2					
Hou et al (2020)[47]	M;▲;2	M;▲;2			M;▲;2	
Otero et al (2018)[92]		L;▲	L;▲			
Ryan (2016)[58]				L;▲;2		
Soto et al (2021)[59]				L;▲;4		
Xu (2019)[62]		L;▲				
Fyhri et al (2016)[86]					L;▲	

***Figure 3:* Effect direction plot of included studies**
Intervention types have been colour coded: environmental is green; settings-based is yellow; communication and education is orange; bicycle-sharing systems or programmes is pink; policy is purple; and multiple blue. Multiple refers to the use of several intervention types; environmental interventions encompass building or improving local routes or networks, and city and town-wide environmental changes; settings-based interventions encompass school and workplace approaches; and communication and education interventions encompass mass media, social media, and education and behaviour-change strategies. L=large sample size (>300). M=medium sample size (50–300). S=small sample size (<50). RCT=randomised controlled trial. *Sample size of intervention group for a given study and outcome domain. †Upward arrow indicates favourable intervention, downward arrow indicates not favourable intervention, and bidirectional arrow indicates no change or mixed effects. ‡Number of outcomes within each category synthesis is 1 unless indicated in subscript beside the effect direction. §Safety outcomes include traffic safety, personal safety, and crime-related safety. ¶Health outcomes include physical health and mental health. ‖Environmental outcomes include pollution and carbon emissions. **Social outcomes include social health and wellbeing and social capital. ††Studies that were designed as RCTs or cluster RCTs. All other studies were quasi-experiments or natural experiments.

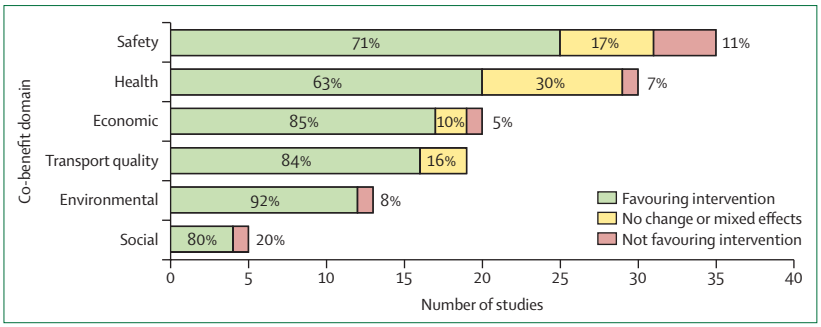


Figure 4: **Overall evidence on co-benefits domains by number of studies**

or injuries)[82] or subjectively (eg, perceived route safety).[84] Of the 35 studies, 25 (71%) reported active travel interventions improving safety (eg, reduced motor traffic volume, fewer accidents or injuries, and improved perceived safety). For example, DiMaggio and colleagues[39] found that the Safe Route to School programme in Texas, USA, led to a reduction in annual rates of pedestrian and cyclist injuries for both children and adults. However, six (17%) studies reported no change or mixed-effect results, and four (11%) reported a not favourable effect. For example, Kang and colleagues[48] found that schools that implemented the Safe Routes to School programme in New York, USA, had unfavourable changes in collision risk compared with the control schools.

Only three studies examined personal safety outcomes in addition to objectively measured traffic safety, all of which concerned perceived safety from crime. One study found an active transport-to-school programme[35] was associated with higher perceived personal safety among schoolchildren and their parents, and another study found an infrastructure improvement programme[75] was associated with higher perceived personal safety among adults. One other study evaluating infrastructural improvements in a school neighbourhood had an overall favourable finding for traffic safety, but parental and child perceptions of personal safety were in different directions of effect.[107]

28 studies examined the physical health outcomes of active travel interventions. Of those, 18 (64%) showed that active travel interventions improved physical health measures. Examples included improved weight-related outcomes among children following a walking school bus intervention[46] and among adults following a bicycle-shaing programme;[62] improved general health among adult participants after a workplace-based e-bike promotion intervention;[53] and improved cardiovascular fitness among children as a result of a school-based active travel intervention.[98] Three studies showed improved uptake of active travel in more disadvantaged groups, suggesting reduced inequities in physical activity and related health outcomes,[69,104,108] whereas two studies showed mixed patterns of findings across priority subgroups.[41,72] Eight studies showed mixed findings, and two showed worsening outcomes, such as lower self-rated health following an urban bicycle infrastructure intervention.[101]

Four studies examined the mental health outcomes of active travel interventions. All these studies reported improved mental health outcomes, including mental health functioning following a self-help workplace intervention;[73] perceived personal wellbeing after a workplace travel behaviour-change intervention;[53] improved quality of life because of a workplace behavioural intervention[67] and an urban bicycle infrastructure intervention.[101]

20 studies examined economic outcomes and of those, 17 (85%) reported favourable economic benefits from active travel interventions. Reflecting the broad range of economic outcomes that have been evaluated, active travel interventions have been associated with cost savings in health-care expenditure,[32] sickness absence,[32] unemployment benefits,[97] and improved productivity.[67] Interventions have also been associated with travel-related cost savings[82] and increased economic activity in the intervention areas (eg, local customer spending[33,109]). Two studies reported no change or mixed-effect results, and one reported an unfavourable economic outcome, where a new light-rail transit line was associated with a larger increase in health-care spending.[61]

19 studies examined transportation quality outcomes specific to active transport, and of those, 16 (84%) reported favourable outcomes. Examples of transportation quality benefits included improved accessibility and mobility,[111] reduced travel time,[112] reported ease and comfort,[44,80] and satisfaction with active travel infrastructure.[63] Three studies reported either no change or mixed effects concerning cycling speed in a cycle lane with minimal traffic.[88] Four studies examined changes in subgroup users (including women, older people, non-White people [as referred to in the study], and people with disability or long-term illness) of transport-infrastructure improvement interventions.[42,58,59,70] One found that the interventions improved equity in transport access,[58] two found mixed results across subgroups,[42,70] and another one had an unfavourable effect on equity as neighbourhoods most in need had the smallest increase in access to bike-sharing programmes.[59]

13 studies examined environmental outcomes. Of those, ten (77%) examined carbon emissions and all found that active travel interventions were associated with reduced carbon emissions. Carbon savings were measured in different ways; for example, as aggregated savings across multiple towns (eg, 17 510 tonnes of CO_2 per annum across three towns),[77] as a range according to different settings (eg, 74·85–47 177 tonnes for workplace projects, and 66·57–388·88 tonnes for school projects),[99] or as an estimate at an individual level (eg, 87 kg CO_2 per e-bike).[86]

Three additional studies examined air pollution outcomes. Two studies found favourable outcomes:

a bicycle-rental programme was associated with reduced particulate matter concentration of 2·5 in the city where the programme was implemented[47] and a small-scale, streetscape active travel intervention was associated with reduced NO_2 emissions along a major road near the site of the intervention.[64] The third study had unfavourable findings according to a subjective appraisal of air pollution.[63]

Five studies examined social outcomes and all but one reported favourable social outcomes of active travel interventions, such as improved social connection,[101] social cohesion,[107] and sociable attitudes of children.[94] One study, however, found that participants living in the intervention area where a new bicycle path was built were less likely to report feeling more connected to their neighbours.[106]

Results from GRADE ratings are presented in table 2. Overall, the certainty rating for active travel interventions resulting in safety, economic, environmental, transportation quality, and social co-benefits is very low. Most studies examining the outcomes were not RCTs (low certainty based on initial rating), and the evidence was further downgraded due to methodological restrictions, such as sample representativeness and attrition. For the studies examining health outcomes, we conducted two separate GRADE ratings: one for RCTs, which we rated high, and the other for non-RCTs, which we rated low and later downgraded to very low due to similar methodological concerns as other non-RCT studies.

We conducted a post-hoc subgroup analysis (appendix pp 100–102) to investigate heterogeneity among study results. For studies with economic, environmental, transport quality, and social outcomes, the number of studies with mixed or negative effects was too small (≤3) to warrant subgroup analysis. For safety and health outcomes, we stratified analysis by several selected attributes that were known to affect consistency in outcomes, such as intervention types or settings, timeframe,[113] types of measures within a co-benefit domain (eg, mental health *vs* cardiometabolic outcomes), and objective versus reported measures for the outcomes (eg, traffic crash data *vs* perceived traffic safety).[114] For studies examining safety and health outcomes, none of the subgroup analyses showed clear patterns that might explain heterogeneity in findings, except that studies with longer follow-up time (≥1 year) seemed to be more likely to show favourable findings, and studies with shorter follow-up time (≤6 months) were more likely to show mixed or unfavourable findings. We also investigated whether heterogeneity across outcomes could be explained by the quality of the studies; however, this did not seem to be the case, even though there was a greater percentage of studies that did not favour the intervention among studies that met a higher proportion of applicable quality criteria (appendix p 102).

	Number of participants (number of studies)*	Comments
Traffic and personal safety		
Very low†	>5700 (35 including 3 RCTs)	Not all quality appraisal criteria applied in every study; where applicable the main concerns related to the representativeness of the sample population; no serious concerns regarding indirectness, imprecision, and inconsistency; publication bias not suspected
Transport quality		
Very low†	>247 (19 non-RCTs)	Not all quality appraisal criteria applied in every study; where applicable the main concerns about methodological limitations related to the representativeness of the sample population; no serious concerns regarding indirectness, imprecision, and inconsistency; publication bias not suspected
Health		
High	~500 (6 RCTs)	No serious concerns regarding risk of bias, indirectness, imprecision, and inconsistency; publication bias not suspected
Very low†	>4500 (24 non-RCTs)	Not all quality appraisal criteria applied in every study; where applicable the main concerns about methodological limitations related to randomisation, exposure, representativeness of the sample population, and attrition or sample size; no serious concerns regarding indirectness, imprecision, and inconsistency; publication bias not suspected
Economic		
Very low†	>3300 (20 including 2 RCTs)	Not all quality appraisal criteria applied in every study; where applicable the main concerns about methodological limitations related to the representativeness of the sample population; no serious concerns regarding indirectness, imprecision, and inconsistency; publication bias not suspected
Environmental		
Very low†	>2400 (13 non-RCTs)	Not all quality appraisal criteria applied in every study; where applicable the main concerns about methodological limitations related to the representativeness of the sample population and exposure; no serious concerns regarding indirectness, imprecision, and inconsistency; publication bias not suspected
Social		
Very low†	~800 (5 non-RCTs)	Not all quality appraisal criteria applied in every study; where applicable the main concerns about methodological limitations related to the representativeness of the sample population, attrition, or sample size and randomisation; no serious concerns regarding indirectness, imprecision, and inconsistency; publication bias not suspected

*An estimate has been provided for the number of participants based on the number of large studies (ie, with more than 300 participants in accordance with the classification developed by Boon and colleagues[29]). †Downgraded once for methodological limitations.

Table 2: **Summary of GRADE ratings by outcomes and certainty of evidence**

Discussion

To our knowledge, this study is the first to systematically review the broad co-benefits of active travel interventions. Based on evidence from 80 intervention studies, we have identified an expansive range of co-benefits that extend beyond physical activity, including safety, health, economic, environmental, transport quality, and social outcomes. The consistency of findings was high in favour of the interventions, particularly pertaining to environmental, economic, and transport quality outcomes. Findings from our study highlight the potential for promoting active travel as a promising strategy to jointly address major challenges in contemporary societies, such as traffic safety and road

congestion, chronic diseases, fiscal constraints, air pollution, and carbon emissions.

Active travel provides a unique opportunity to incorporate regular physical activity into daily life without requiring special skills or substantial monetary or time investments. Therefore, it is recommended by researchers in this field as one of the Eight Investments That Work for physical activity promotion.[6] Considering that active travel interventions often involve diverse sectors such as planning, transportation, health, and education, understanding the broad societal benefits beyond physical activity is crucial for cross-sectoral engagement and investments. WHO recommended highlighting social, environmental, and economic co-benefits in communication and advocacy for physical activity to engage policy makers and communities.[4] THE PEP, serviced by WHO Europe and UN Economic Commission for Europe, is an example of an intersectoral project that brings together the transport, health, and environment sectors to better understand the co-benefits of active travel to inform transport, mobility, and urban planning policies.[11]

Our systematic review addresses a much-needed evidence gap, and several main findings should be emphasised. First, we identified many co-benefits of active travel interventions in various outcome domains. The breadth of co-benefits extends beyond the triple bottom-line framework (eg, evaluating the social, environmental, and financial outcomes),[115] and addresses several UN SDGs (such as sustainable cities, sustainable communities, and climate action).[21] In most cases, the evidence consistently favoured the intervention, particularly regarding environmental, economic, and transport quality outcomes. This finding highlights the potential for harnessing the co-benefits of active travel to advocate for policies, programmes, and investments that encourage a modal shift away from car use. Second, nearly two-thirds of the studies either occurred within the built-environment setting or applied built-environmental approaches. This finding might suggest that the built environment is a natural entry-point for understanding the co-benefits of active travel interventions. This finding might also be because much research in the built-environment field tends to be conducted with interdisciplinarity or within non-health disciplines (eg, urban planning or transportation), of which the outcomes of interest are likely to be beyond physical activity. Third, subgroup analysis suggested that interventions are more likely to have favourable results if the outcomes were examined or modelled over the long term than the short term. For example, 22% of the interventions that evaluated health outcomes had favourable results if the follow-up timeframe was within a year, as compared with 75% for studies with a follow-up timeframe of 1–9 years. This finding, which is supported by the literature,[113] highlights the importance of long-term evaluation in active travel interventions, as it could take time to change travel behaviour, as well as improve health and other co-benefit outcomes. Fourth, most of the co-benefits included in the reviewed studies are established outcomes that can be easily measured with validated instruments. Outcomes that are harder to measure, albeit important (such as social benefits), are less studied, representing an opportunity for future research. Fifth, only nine of the identified 80 studies examined whether active travel interventions affected priority subgroups differently, all of which involved built-environment and infrastructure improvements. Previous research has found that population-level interventions that incorporate structural environmental changes are more likely to be effective for improving health outcomes among lower socioeconomic groups (thus reducing inequity), than interventions that focus on individual behaviour change.[116,117] Such research highlights the potential for environmental interventions to help close socioeconomic gaps in the context of health. However, although some studies in our review found favourable effects on equity, others reported mixed effects depending on the subgroup, which reinforces the need for future studies to consider equity during the design, implementation, and evaluation of active travel interventions. Finally, most of the evidence came from North America and Europe and all studies were conducted in high-income countries except for one study conducted in China,[108] one in Serbia,[90] and another in Lebanon.[109] This fact suggests an inequity in research and evaluation in this area, which echoes the research landscape overall.[118] Without such data, it is impossible to establish whether active travel interventions are likely to produce similar or different co-benefits in low-income and middle-income countries.

Our review has few limitations following a comprehensive search strategy that captured a broad range of studies across disciplines. First, despite preregistering the review protocol with PROSPERO, we made some modifications since the commencement of the literature review. We have documented these changes and their rationales (appendix p 2). Second, due to the heterogeneity of the

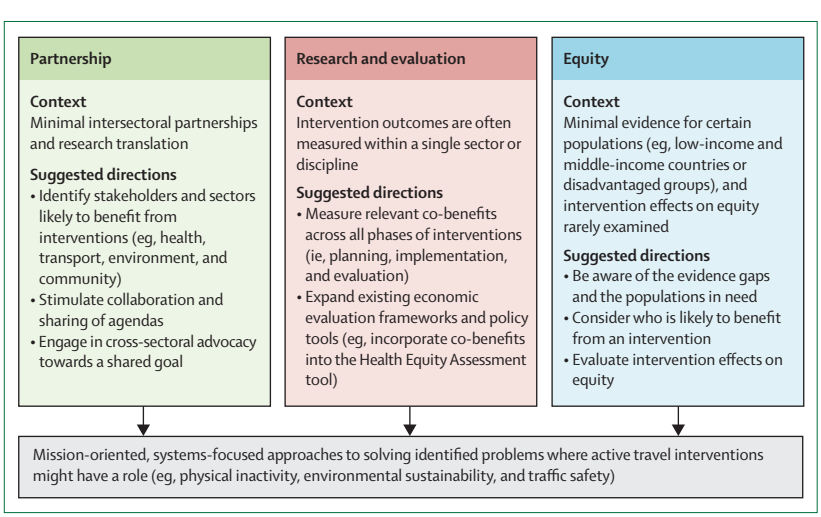


Figure 5: **Research, policy, and practice recommendations for co-benefits of active travel interventions**

studies and their outcomes, a meta-analysis could not be conducted. Instead, we applied an established vote-counting method to synthesise the results with an effect direction plot as recommended by the Cochrane Handbook.[29] Although this updated method has addressed the problems with previous vote-count methods, such as relying on statistical significance and other subjective rules, constraints still apply, such as not being able to incorporate the magnitude of effects in the synthesis of evidence.

The overall certainty of the evidence as assessed by GRADE is very low for most outcomes, despite the overall consistent findings from the effect direction plots. Such a low rating was due to methodological limitations (ie, 88% of the included studies were non-RCTs) and should be interpreted within the context of the intervention types. First, for most studies involving the built environment (eg, improvement of networks and city-wide or town-wide environmental changes) or policy changes, conducting an RCT is not practical or feasible, and is sometimes unethical. Therefore, non-RCT designs, such as natural experiments, are crucial for informing real-world decisions regarding programmes, policies, and practice.[119] Although the GRADE approach is considered by many international organisations to be the best practice for assessing certainty of evidence,[120] it automatically downgrades evidence from non-RCTs. Alternative evaluation frameworks should be developed to assess the quality of evidence of interventions operating at the outer levels of the socioecological models, which is an approach that has been adopted for infectious disease prevention and control interventions.[121] Second, although quasi-experimental and natural-experimental studies are often considered to be among the most robust and feasible designs when evaluating the effects of the built environment,[122] many existing studies still have further methodological limitations, such as a lack of population-representative samples or comparable controls. Third, despite not limiting the searches by language or publication type (eg, peer-reviewed papers or grey literature), the existing evidence base disproportionately over-represents high-income countries, raising questions about the generalisability of such evidence to most of the world's population. Considering that low-income and middle-income countries bear most of the disease burden from an inactive lifestyle,[123] as well as being disproportionately affected by the negative consequences of environmental and societal challenges (such as climate change, air pollution, traffic congestion, and safety),[21] evidence from these countries is urgently needed.

As the first systematic evidence synthesis of co-benefits of active travel interventions, our study has important policy implications. Our findings suggest that active travel could be an important focal point to synergistically address multiple societal challenges, such as health, traffic safety, air pollution, and climate change. Mission-oriented approaches have been recommended for addressing such challenges; these are solution-oriented, time-bound, and outcome-focused, emphasising cross-sectoral collaboration to develop comprehensive solutions.[124] Our study provides support for applying these approaches to address identified challenges (eg, physical inactivity and environmental sustainability) of which active travel interventions are pivotal by improving understanding of the multiple co-benefits of such interventions.[125] We recommend several key directions for research, policy, and practice (figure 5), including the use of co-benefits evidence, such as that identified by the current study, to identify potential collaborators, develop intersectoral partnerships, and work collectively towards a shared goal. We also recommend that co-benefits be considered through all phases of interventions and policy making. Existing economic evaluation frameworks and policy tools (eg, the Health Economic Assessment Tool for walking and cycling)[126] should incorporate additional co-benefits to broaden the consideration of societal benefits. Finally, future interventions, programmes, and policies should be designed, implemented, and evaluated with a focus on equity to ensure that social inequalities are not widened as an unintended consequence.

Contributors

Conceptualisation, study design, and search protocol development: DD, TN, and BN. Funding acquisition: DD. Writing, literature searches, and screening: TN, BN, ML, and DD. Data extraction and data synthesis: TN, BN, and ML. Risk of bias assessment: BN, MFPI, and ML. Search protocol revision, overall revision, and final approval: all authors.

Declaration of interests

DS received royalties for a textbook from the publisher Human Kinetics and speaker honoraria for a keynote presentation in Chile; travel funds to teach a methods course at the National Institute of Public Health of Mexico; is an executive board member of the International Society of Behavioral Nutrition and Physical Activity; and is chair of The Council on Environment and Physical Activity. BZ-D received consulting fees from Public Health England. All other authors declare no competing interests.

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