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The impact of e-cycling on travel behaviour: A scoping review

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ABSTRACT

Introduction: Electrically assisted bicycles (e-bikes) have become increasingly popular in the past decade. This review aimed to scope the literature to identify what is known about the frequency and duration of e-bike use, their impact on travel behaviour, the purposes for which e-bikes are used and factors associated with e-bike use. In addition, the review aimed to identify gaps in the literature and highlight future research priorities.
Methods: A scoping review of published and unpublished literature in any language. Relevant articles were identified through searching six databases, two grey literature platforms and reference lists. Searches were conducted until August 2019. Data were extracted using a standardised extraction form and descriptive and narrative results are provided.
Results: Seventy-six studies met the inclusion criteria. The volume of research has increased since 2017 and primarily examines personal e-bike use, as opposed to e-bike share/rental schemes or organizational e-bike initiatives. The use of e-bikes increased the frequency and duration of cycling compared to conventional cycling and may help overcome barriers associated with conventional cycling. The uptake in e-cycling largely substitutes for conventional cycling or private car journeys, though the degree of substitution depends on the primary transport mode prior to e-bike acquisition. E-bikes are primarily used for utilitarian reasons, though older adults also engage in recreational e-cycling. Research priorities include quantitatively examining e-bike use, their impact on overall transport behaviour and identifying determinants of e-cycling to inform intervention and policy.
Conclusions: This review suggests that the personal use of e-bikes is associated with a reduction in motorized vehicle use, which has potential positive impacts on the environment and health. The impacts of e-bike share schemes and workplace initiatives are less well understood. Evidence describing the purposes for which e-bikes are used, and the factors associated with usage, are useful to inform e-cycling promotion policy.

1. Introduction

Travel is an essential part of everyday life for most people. Motorized road travel is a major use of energy, creating air pollution and

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contributing to global warming (Fuglestvedt et al., 2008). Vehicles in congestion emit more pollution than free-flowing traffic (Zhang et al., 2011), which is of concern given that traffic levels, and associated congestion, are expected to rise in many developed countries including the UK (Department for Transport, 2018a), Europe (European Commission, 2019), Australia (Bitre, 2015b) and the United States (Federal Highways Administration, 2020).

Adoption of active travel, such as walking and cycling, may contribute to reducing congestion, greenhouse gas emissions and air pollution, while also having a positive impact on health through increased physical activity (Woodcock et al., 2009; Neves and Brand, 2019). Consequently, understanding ways to increase active travel is important to transport policy makers, urban planners and health care professionals (Laird et al., 2018). Furthermore, active travel has been highlighted as a means of reducing public transport use and the associated potential transmission of covid-19 and is being actively encouraged by the UK government (Department for Transport, 2020).

However, public engagement in active travel, in particular cycling, is often low (Cavill et al., 2019; Strain et al., 2016; Buehler and Pucher, 2012). In Europe 12% of 27,680 individuals across 28 member states reported cycling every day (European Commission, 2013). However, large variations in reported cycling exist in Europe with Spain (4%), Luxembourg (4%), and England (2%) reporting the lowest rates of daily cycling while the Netherlands (43%), Denmark (30%) and Finland (28%) reported the highest rates of daily cycling (European Commission, 2013). Specifically, in England in 2017 26% of yearly trips were made on foot and 2% on bicycle, accounting for 3% of total distance travelled (Department for Transport, 2018b). In the United States fewer than 3% and 1% of the population commuted to work on foot or by bike respectively (League of Amercian Bicyclists, 2019). Commonly reported barriers to active travel include the distance people must travel, lack of time, hilly terrain, and the undesirability of being out of breath or sweaty when arriving at a destination (De Geus et al., 2018; Van Cauwenberg et al., 2018a).

Electrically assisted bicycles (e-bikes) are a more environmentally friendly and sustainable mode of transportation than motorized vehicles, while providing at least moderate intensity physical activity (Bourne et al., 2018). The term e-bike includes a range of designs including solely throttle-controlled bikes, which do not require the rider to pedal or those which provide electrical assistance only when the rider is pedalling. E-bikes which require the user to pedal have lower motor power and maximum speeds compared to throttle-controlled bikes and are therefore legally classified as bicycles (Fishman and Cherry, 2016). Such bikes enable the user to maintain speed with less effort, overcoming some of the barriers to traditional cycling (Fishman and Cherry, 2016) and may encourage individuals to participate in active travel in place of motorized travel. For this review we consider only e-bikes that require the user to pedal for assistance to be provided.

E-cycling is increasingly popular, with 40.3 million e-bikes expected to be sold globally in 2023 (Statista, 2015). With this rise in popularity it is important for authorities to understand where e-cycling fits within current mobility patterns. This will assist in decision-making regarding investment in e-cycling infrastructure and help determine whether strategies to promote e-cycling are appropriate. It is also important to ascertain whether adoption of e-cycling impacts the sedentary behaviour of motorized vehicle use by replacing some car journeys, potentially reducing both motor vehicle congestion and pollution. In contrast, if e-cycling replaces conventional cycling and walking therefore representing a distraction from the improvement of current cycling and walking infrastructure and initiatives that may increase active travel.

An individual's transport mode choice depends on the travel need (e.g., commuting, shopping, escorting children) and specific trip attributes (including distance, location and time requirements (Götschi et al., 2017)). It is therefore important to understand how e-bikes are used (regarding distances travelled and duration of rides) and the purpose of their use to understand the contexts in which e-bikes could be incorporated into current travel systems.

In addition to objective travel choices, the decision to engage in e-cycling is likely to be determined by a series of perceptions regarding the individual and the environment. As such studies have begun to explore motivation for e-cycling and experiences of engaging in e-cycling to understand why individuals engage in this activity (Fishman and Cherry, 2016). To date, however, review evidence exploring the factors associated with e-cycling, and how engaging in e-cycling impacts travel behaviour, has not been conducted. Collectively, this information is important to guide future planning initiatives and health promotion campaigns.

A review of the literature will help to map the available evidence to document our current knowledge of how e-bikes are used (i.e., frequency and duration of e-cycling), the purposes for which e-bikes are used, their impact on travel behaviour and to identify potential determinants of e-bike use. In addition, a review will help identify gaps in the literature and highlight future research priorities.

2. Methods

A scoping review was selected as the most appropriate review method for addressing the research aims (Peterson et al., 2017, Grant and Booth, 2009). The 5-stage methodological framework proposed by Arksey and O'malley (2005) and developed by Levac, Colquhoun & O'Brien (2010) was adopted to guide this scoping review. Reporting of the scoping review followed the PRISMA Extension for Scoping Reviews guidelines (Tricco et al., 2018).

2.1. Stage 1: identifying the research question

A number of research questions were formulated to summarise the evidence. From the existing literature this review will determine:

- What is known about the frequency and duration of journeys made by e-bike?
- What is known about the purpose of e-bike use?

- What is known about the impact of e-bike use on overall travel behaviour?
- What is known about individual's motivation for e-cycling, experiences of engaging in e-cycling (specifically barriers and benefits to engaging in e-cycling) and general attitudes towards e-bikes and e-cycling?
- What are the current evidence gaps and research priorities?

2.2. Stage 2: identifying relevant studies

2.2.1. Identify relevant outcomes

The review included studies that provided data/results relevant to any of the research aims or questions. This included self-report or objective measures of the impact of having access to an e-bike on the use of the e-bike, and alternative modes of transport and the purpose of e-bike trips (e.g., recreation, commuting, errands etc.). In addition, outcomes related to the motives for e-cycling, experiences of engaging in e-cycling and general attitudes towards e-bikes and e-cycling were included. Studies that reported future preferences for e-cycling, without having had access to an e-bike were not included as these data would not assess actual impact.

2.2.2. Types of sources

Peer-reviewed primary research including both experimental and non-experimental studies, including cross-sectional and longitudinal quantitative and qualitative studies were considered for inclusion. Theses (PhD, MSc, MPhil or BSc), project reports or presentations and conference proceedings were considered for inclusion. Review articles were screened for appropriate references but not included in the review. Studies published in any language were considered. Editorials, opinion pieces and commentaries were not included.

2.2.3. Types of participants

Studies with adults over 18 years of age, healthy or with long-term health conditions were included. Eligible adult participants were owners of an e-bike or had regular access to an e-bike (e.g., were part of an e-bike sharing scheme, rented an e-bike or were provided with an e-bike as part of an intervention).

2.2.4. Context

Only studies of e-bikes that had pedals and were operated in part by the individual (i.e., some amount of energy, above resting metabolic rate, must be expended when cycling) were included. Studies including e-bikes operated solely by a motor, not requiring pedalling, were excluded.

2.2.5. Search strategy

The following databases were searched from 1989 (the date the first e-bike was produced) to the present day: Elsevier Science-Direct, ISS Web of Science, ProQuest, EMBASE, MEDLINE (via Ovid) and Scopus. Search terms pertained to e-bikes only to keep the search as broad as possible. A list of search terms is provided in supplementary file 1. OpenGrey and Google Scholar (first 20-pages) were searched using the term '*electrically-assisted bicycle*'. The reference lists from all selected articles were hand-searched for relevant studies. Searches were run up to August 2019.

2.3. Stage 3: study selection

All identified records were uploaded to the online software Covidence (https://www.covidence.org). Duplicate publications were removed, and two reviewers (JEB and ARC) then independently conducted title and abstract screening. These reviewers met following completion of 20% and 50% of screening to assess agreement. Full texts were sourced, and when required, translation was conducted by individuals fluent in reading and speaking the required language in addition to English. Full-text screening was conducted independently by two reviewers (JEB and CE) who met at 25% and 50% of full text screening to assess agreement. Where findings from conference proceedings were superseded by a project report or published literature data from the earlier conference proceeding was not reported.

Scoping reviews are typically iterative given the increased familiarity of the researchers with the evidence as the review progresses (Arksey and O'malley, 2005). In the current review much of the evidence failed to report on the characteristics of the e-bikes being investigated. In North America and Europe, the predominant e-bike design has pedals and the rider must pedal for power to be provided. In China, however, e-bikes are predominantly throttle powered and do not require pedalling (Fishman and Cherry, 2016). As such, unless specifically stating the type of e-bike used, studies conducted in Europe and North America were included, while those conducted in China were excluded.

2.4. Stage 4: charting the data

A data extraction chart was created and reviewed by all authors prior to data extraction. The following data were extracted from each article: author(s), year and type of publication, location, study aims, study design, study methodology, sample size and characteristics, outcomes measured and key findings. Data extraction was conducted by two reviewers in a stepwise fashion. Specifically, JEB extracted data from 100% of included studies and FJK then extracted data from 25% of these studies to check for accuracy. Any discrepancies were discussed and resolved.

2.5. Stage 5: collating, summarizing, and reporting the results

A descriptive analysis was conducted to provide information on the volume of included studies by year of publication, location of study, study methodology and outcomes examined. Where behavioural outcomes were examined using qualitative methods these results were incorporated into a descriptive summary. For motivation, experience and attitude outcomes examined using qualitative methods, information was characterised by identifying the main themes reported by authors. Common themes across studies are presented. The review of qualitative research to identify the main themes was conducted by two reviewers (JEB and FJK), and a narrative summary is provided for each outcome reviewed. The meaning of the findings in relation to the overall research question and the broader implications for research, policy and practice is discussed, including identification of relevant evidence gaps and priorities.

3. Results

3.1. Articles retrieved

In total 4043 records were identified from database and grey literature searches. After duplicates were removed 2841 records remained and underwent title and abstract screening (see Fig. 1 for review flow diagram). A total of 181 articles underwent full test screening. Of these, 61 articles were considered relevant to the aims and were included in the review. Reference lists of eligible studies were searched, and an additional 16 articles were identified for inclusion in the review. Of the 77 articles for inclusion in the review one could not be sourced (Wright, 2013), leaving 76 for inclusion in the analysis.

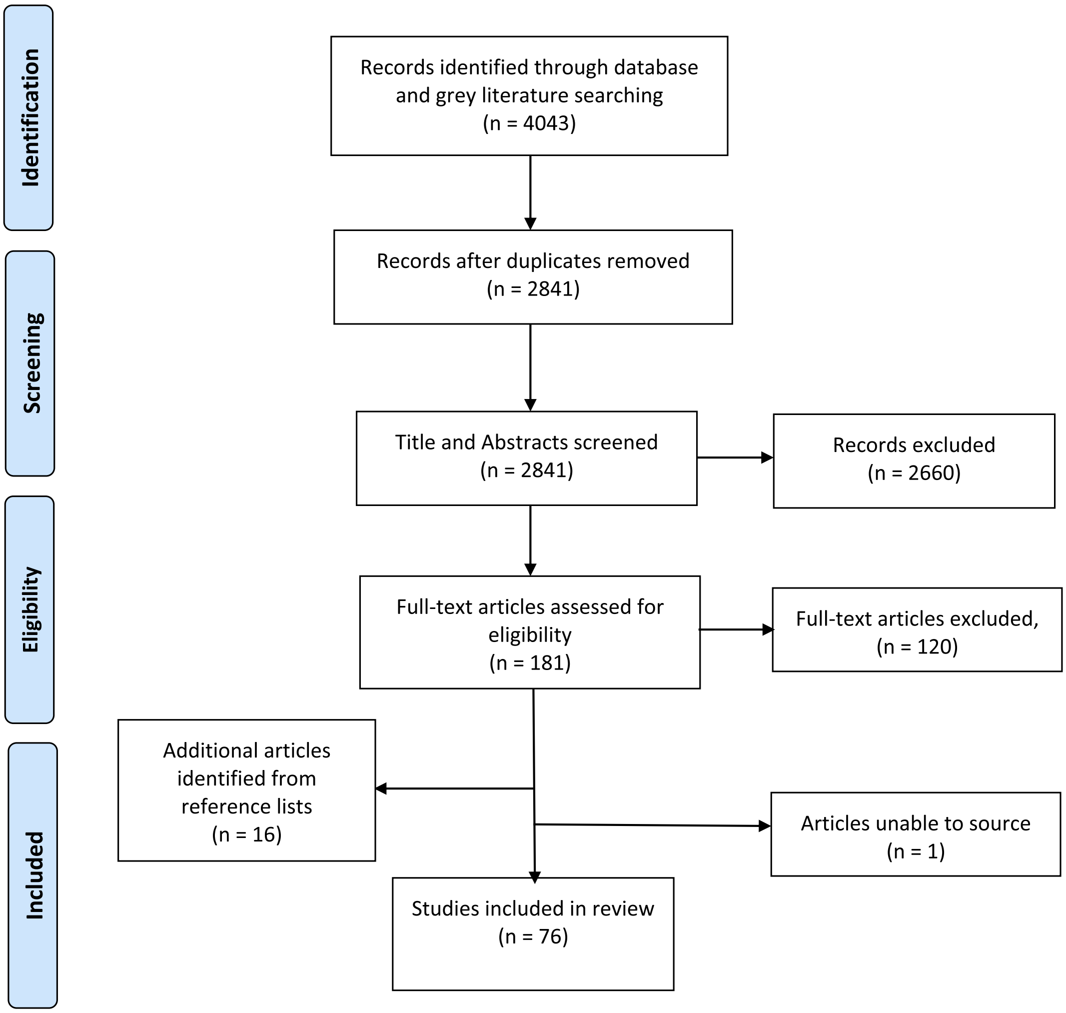

Fig. 1. Flow diagram of scoping review article identification.

3.2. Article characteristics

Articles were identified from 17 countries. A total of 80.3% of the articles originated from Europe (n = 61), 17.1% from North America (n = 13) and 2.6% from Australia and New Zealand (n = 2). Five articles (6.6%) were published between 2003 and 2010, all of which originated from Europe, with the remaining articles (93.4%) published from 2011 onwards. Fig. 2 shows the chronological increase in papers reporting relevant outcomes from 2003 to August 2019.

Of the 76 articles, 48 were peer-reviewed research papers, drawn from 40 studies and 28 were from grey literature. Most of the peer-reviewed research has been published in transport related journals (see Table 1) and has increased substantially since 2017 (see Fig. 2). The grey literature comprised five published conference proceedings, four theses, 17 project reports and two project presentations. Of the 68 unique studies identified 40 had a non-experimental design (30 cross-sectional, 10 longitudinal) and 28 were experimental. Most studies (n = 65) examined outcomes associated with personal e-bike use. Eight studies examined the impact of e-bike share or rental schemes and three studies examined workplace e-bike initiatives.

Non-experimental studies: Findings from non-experimental studies on personal e-bike use (n = 31) are reported in supplementary file 2. One study examined the experiences of students' use of e-bikes and two explored e-cycling in older adults. The remaining studies did not specify participants age; however, demographic data showed that most e-bike users were ≥40 years of age. The percentage of female e-bike users in the studies ranged from 15 to 56%. A 2014 survey of e-bike owners in USA reported 15% of the sample were female (MacArthur et al., 2014). When the survey was repeated in 2018, 28% of the sample were female (MacArthur et al., 2018). Samples sizes ranged from 11 to 1796. Nine studies compared e-bike use to conventional bike use. Non-experimental studies from e-bike rental/share schemes (n = 8) and workplace e-bike initiatives (n = 1) are reported in supplementary files 3 and 4, respectively.

Experimental studies: The populations targeted by experimental studies examining personal e-bike use (n = 26) were highly heterogenous (see supplementary file 5). Populations studied included university staff and students (n = 3), university students exclusively (n = 1), older adults (n = 1), inactive adults (n = 4), individuals with type 2 diabetes mellitus (n = 1), stroke survivors (n = 1), company employees (n = 4), commuters (n = 4) and parents (n = 1). Two studies provided families with electric vehicles on loan with the inclusion of e-bikes (Cellina et al., 2016; Kroyer and Johansson, 2013). One study required participants to hand over the keys to their motor vehicle in exchange for an e-bike (Moser et al., 2018). E-bike loan periods varied in length from one day to three years. The percentage of females in experimental studies ranged from 0 to 80% and sample sizes ranged from three to 1854. Experimental studies from workplace e-bike initiatives (n = 2) are reported in supplementary file 4.

3.3. What is known about the frequency and duration of e-bike use?

Sixty-one studies (80%) reported e-bike use following the acquisition of an e-bike. E-bike use was primarily measured using self-report online or paper questionnaires. Four non-experimental studies recorded e-bike use using GPS tracking and three with travel logs. Ten experimental studies used GPS tracking or bicycle odometer measurements and eight used travel logs including smartphone applications. The types of e-bike use outcomes reported were highly heterogenous with varying time scales and distance measurements reported.

Reported mean daily distances travelled on the e-bike ranged from 2.7 km to 24.0 km, with the majority of studies (n = 20) reporting mean daily distances between 3 km and 11.5 km. Frequency of e-bike use ranged from 1.9 to 5.1 days per week. Haustein and Møller (2016a) reported that recreational riders cycled further distances per trip compared to those that used the e-bike for utilitarian purposes (e.g., commuting, shopping, running errands). While Winslott Hiselius and Svensson (2017) reported that e-bikes were used for commuting on 3.6 days per week and for leisure on 1.4 days per week.

Participants cycled longer distances on an e-bike compared to a conventional bike. In a randomized controlled trial in which adults had access to an e-bike or conventional bike for 3-months the median distance cycled per week on the e-bike was 20.2 km compared to 11.9 km on the conventional bike, with individuals spending longer on the e-bike (62.7 min) compared to the conventional bike (51.1 min (Bjørnarå et al., 2019)). Similarly, in a study conducted in seven European countries, Castro et al. (2019) reported that e-cyclists average daily travel distance was 8.0 km compared to 5.3 km for conventional bike commuters. In addition, individual trip distances and duration of rides on e-bikes were longer than those on a conventional bike (Castro et al., 2019, Mobiel 21, 2014). In a number of studies participants also self-reported increases in cycling frequency and/or duration following the acquisition of an e-bike (Dill and Rose, 2012; Hendriksen et al., 2008; Kroyer and Johansson, 2013; Fyhri et al., 2017, MacArthur et al., 2018).

The majority of evidence suggested that men ride an e-bike more frequently and further than women (Cooper et al., 2018; Bundesamt für Umwelt, 2004; Van Cauwenberg et al., 2018; De Geus et al., 2013; De Kruijf et al., 2018; Jahre et al., 2019). However, Cappelle (2003) found that women (mean age = 46 years) cycled more frequently than men, while Castro et al. (2019) reported that more women were e-bike and conventional bike users than men in a sample of similar age.

Few studies have compared e-cycling between different age groups, of those that have the evidence suggested that younger adults cycled longer distances than older adults (Bundesamt für Umwelt, 2004) and that as age increases there is a decrease in e-bike use (Kroesen, 2017).

In the workplace, e-bikes were used for work travel by employees in the two studies that provided e-bikes as company transport (Prill, 2015; Kroyer and Johansson, 2013). When e-cargo bikes were introduced as a replacement for conventional bikes or cars/vans in a 2-year trial, 147 of 362 messengers rejected the adoption of the bike, with 48.3% reporting a preference to use the car or van (Gruber and Kihm, 2016).

Six of the eight studies examining e-bike rental/share schemes reported e-bike use. Distances covered on the e-bikes ranged from 2 to 10 km. In the two studies that compared e-bike to conventional bike share, the authors reported that individuals travelled further on

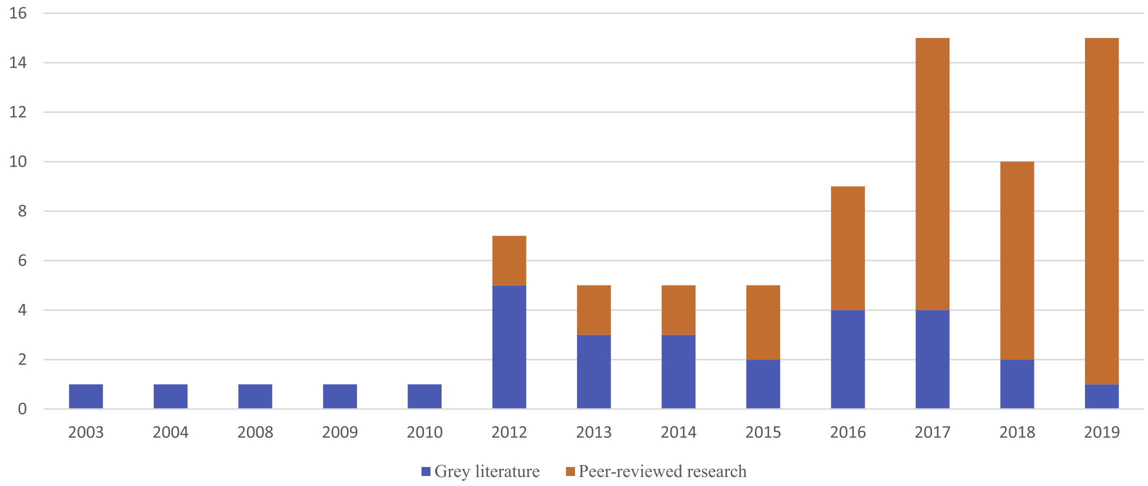

Fig. 2. Included studies by year of publication and article type.

Table 1
List of journals in which primary literature has been published.

Journal	Number of articles published
Acta Kinesiologiae Universitatis Tartuenis	1
British Journal of General Practice Open	1
BMC Public Health	1
Clinical Journal of Sport Medicine	1
Diabetic Medicine	1
Environmental Research Letters	1
European Journal of Applied Physiology	1
European Journal of Sport Science	1
Frontiers in Psychology	1
International Journal of Sustainable Transportation	3
International Transportation	1
Journal of Advanced Transportation	2
Journal of Adventure Education and Outdoor Learning	1
Journal of Cleaner Production	1
Journal of Transport and Health	3
Journal of Transport Geography	2
Medicine and Science in Sport and Exercise	1
Mobilities	1
PLOSone	2
Preventive Medicine Reports	1
Sustainability	2
The Canadian Geographer	1
Transportation Research Record	1
Transportation	1
Transportation Research Interdisciplinary Perspective	1
Transportation Research Part A	3
Transportation Research Part D	3
Transportation Research Part F	1
Transportation Research Procedia	1
Transportation Research Record, Journal of the Transportation Research Board	4
Travel Behaviour and Society	3

the e-bike than they did on a conventional bike (Langford et al., 2013; Bikeplus, 2016).

3.4. What is known about the purpose of e-bike use?

Forty-one studies (54%) reported on the purpose of e-bike use using mostly self-reported retrospective measures including questionnaires and travel diaries. E-bikes were used for a wide range of purposes including commuting, shopping, visiting friends and family and recreation. However, e-bikes appear to be used more frequently as a utilitarian mode of transport rather than for a leisure activity. Studies with samples aged ≤55years reported the e-bike being used primarily for commuting (Dill and Rose, 2012; Winslott Hiselius and Svensson, 2017; MacArthur et al., 2014; Plazier et al., 2017a; Popovich et al., 2014; Schleinitz et al., 2014; Cappelle et al., 2003; Kairos, 2010; MacArthur et al., 2018; Lobben et al., 2019; Behrendt, 2018; Sundfør and Fyhri, 2017) whilst older adults used the e-bike for shopping and visiting friends but rarely for commuting. In addition, older adults used the e-bike for recreational purposes. Whether e-bikes were primarily used for recreation or running errands in older adults varied across studies (Hendriksen et al., 2008; Van Cauwenberg et al., 2018; Johnson and Rose, 2015; Leyland et al., 2019; Wolf and Seebauer, 2014). Few studies have examined how the purpose of e-bike use differs between genders. Among older adults Van Cauwenberg et al. (2018) reported that women used the e-bike for more social visits than men.

In the workplace e-bikes were used for commuting, travelling between offices and to meet customers (Kroyer and Johansson, 2013; Prill, 2015). Of the three studies that examined the purpose of using an e-bike share scheme uses varied and included shopping, running errands, commuting to work or school or for recreation (Munkacsy and Monzon, 2017; Langford et al., 2013; He et al., 2019).

3.5. What is known about the impact of e-bikes on travel behaviour?

Forty-two studies (55%) examined the impact of e-bike use on other travel modes. The degree to which e-bikes replaced alternative transport modes varied across studies. However, the evidence suggests that the car and conventional bicycle were the most substituted modes of transport following acquisition of the e-bike.

The proportion of e-bike trips previously conducted by conventional bicycles ranged from 23% to 72% of total trips. Among older adults Van Cauwenberg et al. (2018) reported that 72% of conventional bike trips were replaced by the e-bike, with those who were conventional cyclists prior to acquisition of an e-bike reporting greater e-bike substitution than non-cyclists (Johnson and Rose, 2015).

The proportion of car journeys substituted following acquisition of an e-bike ranged from 20% to 86%, with three studies reporting the substitution of short car journeys with the e-bike[1] (Lee et al., 2015; Edge et al., 2018; Kroyer and Johansson, 2013). E-bikes also substituted for public transport with the proportion of journey substitution ranging from 3% to 45%. Few studies have found e-cycling to impact walking with the exception of one study conducted in the UK in which low levels of driving and high levels of walking were reported prior to the provision of e-bikes compared to the rest of the country (Cairns et al., 2017). In this study 38% of the sample reported a reduction in walking following the acquisition of an e-bike. Castro et al. (2019) note that the impact of the e-bike on travel behaviour is largely influenced by the primary mode of travel prior to the introduction of the e-bike. Specifically, in Antwerp e-bikes primarily substituted for conventional bike journeys (34%) and private car journeys (38%), while in Zurich, the e-bike primarily substituted for public transport journeys (22%). Across the 7 cities the authors reported that the degree of substitution of car, conventional bike or public transport journeys was 2–49%, 5–60% and 6–35% respectively. The mode of transport being substituted was still used extensively in addition to the e-bike. Winslott Hiselius and Svensson (2017) reported that the impact of e-bikes on travel behaviour differed between rural and urban areas of Sweden. In rural areas the e-bike substituted 71–86% of car trips compared to 42–60% of car trips in urban areas. In urban areas the e-bike also substituted for conventional cycling and public transport. No studies have examined the differential impact of e-bike use on travel behaviour based on gender.

In the workplace e-bikes replaced car journeys or conventional cycling (Prill, 2015; Kroyer and Johansson, 2013). Regarding e-bike share or rental schemes on university campus 57% of walking trips were substituted with the e-bike (Langford et al., 2013), while in Madrid e-bikes substituted similarly for public transport and walking, the primary modes of city travel (Munkacsy and Monzon, 2017). In the UK 11 bike share projects, Bikeplus (2016) reported that e-bike trips primarily substituted for car trips, the primary mode of transport in UK cities (Department for Transport, 2019b).

3.6. What is known about e-cyclists motivation for e-cycling?

Twenty-eight studies (37%) examined participants' motivation for riding or purchasing an e-bike. Motivation for using or purchasing an e-bike was commonly reported in relation to overcoming barriers to conventional cycling. These included the ability to overcome hilly terrain, to ride with less effort and to complete longer and/or faster trips. The ability to reduce travel time was an important motivational factor for younger adults. In addition, younger adults were more motivated to use an e-bike due to environmental concerns, to reduce car use and to save money compared to older adults. Older adults were motivated to e-cycle as it provided them with the ability to continue to ride despite physical limitations and the potential to maintain or increase physical activity and fitness. Few studies examined differences in motivational factors between genders. However, MacArthur and colleagues (2014, 2018) reported that females were more likely to buy an e-bike to overcome hilly terrain and to ride with friends and family compared to men.

In the workplace, motivation for e-cycling included sustainability and better mobility around the city (Prill, 2015) and a preference for e-cycling over using the car or conventional bicycle (Kroyer and Johansson, 2013). Of the two studies that reported on motivation for using e-bike share schemes, the primary motivation for use was that e-cycling was faster than alternative transport modes, thereby reducing travel time and being more convenient (Langford et al., 2013; Bikeplus, 2016).

[1] These studies do not provide a definition of what constitutes a short car journey.

3.7. What is known about the experience of engaging in e-cycling?

3.7.1. Benefits of e-cycling

Forty-three studies (57%) explored participants reported benefits of e-cycling. Table 2 provides an overview of the reported individual, social and physical benefits of e-cycling. Participants discussed the benefits of e-cycling in comparison to other transport modes. Specifically, e-cycling required less physical effort than conventional cycling due to the assistance provided and was associated with reduced perspiration. The extra assistance, and reduced effort, enabled participants to travel longer distances and/or decrease their travel time in comparison to conventional cycling. E-bike users were able to ride hilly terrain and take more direct routes to their destination. E-cyclists felt safer and more confident riding an e-bike on busier streets in comparison to a conventional bike due to the ability to keep up with traffic and accelerate faster at traffic lights. E-cycling saved time compared to the car or conventional bike and was perceived as being less restricted by parking or congestion compared to motorized transport.

The e-bike enabled individuals who cannot ride a conventional bicycle to begin riding or who were considering giving up conventional cycling to continue riding. The only reported social benefit of riding an e-bike was the ability to ride with friends and family. Specifically, e-bikes removed differences in riding abilities due to fitness or physical limitations between riders enabling unfit individuals to keep up with fitter individuals riding a conventional bike. The enjoyment and fun associated with e-cycling was the most consistently reported benefit across all studies.

Few studies examined differences in perceived benefits of e-cycling based on age or gender. Van Cauwenberg et al. (2018) found no differences in reported benefits of e-cycling between older men and women. Regarding age, in three studies that focused exclusively on older adults (Van Cauwenberg et al., 2018; Johnson and Rose, 2015; Leger et al., 2019) the ability to cycle longer distances was a consistently reported benefit. In studies with younger samples (i.e., 40–60 years of age) the time savings accrued from e-cycling, in comparison to conventional cycling and a car was a common benefit, with e-cycling providing more predictable journey times.

Similar benefits of e-cycling were reported in workplace initiatives. In addition, participants reported greater autonomy in comparison to travelling by public transport or carpooling and the e-bike enabled easier access around the city, avoiding parking problems (Prill, 2015; Kroyer and Johansson, 2013). In Madrid, the e-bike share scheme provided a faster and more economical mode of transport in comparison to walking or public transport (Munkacsy and Monzon, 2017). In a rental scheme in the UK, e-bikes provided participants the opportunity to ride with friends and family and those of higher fitness levels than themselves (Sustrans, 2013).

3.7.2. Barriers to e-cycling

Thirty-seven studies (49%) explored participants barriers to e-cycling. Most of the barriers reported related to the e-bike itself or the

Table 2
Benefits of e-cycling, (the number in brackets represents the number of studies reporting that specific benefit).

Individual	Social	Physical	Most commonly reported ↑
Fun/enjoyment (21)	Ability to ride with friends and family (12)	Ability to ride longer distances than conventional bicycle (20)	
Reduced perspiration in comparison to conventional cycling (15)		Faster journeys compared to conventional cycling, walking and sometimes cars (18)	
Reduced overall effort in comparison to conventional cycling (12)		Ability to ride hilly terrain (12)	
Improved health (physical and mental) (9)		Time saving in comparison to conventional bicycle or car (8)	
Ability to continue to cycle despite physical limitations (8)		Ability to ride new routes and to new destinations due to speed and less impact from terrain (9)	
Increased feelings of safety in comparison to conventional cycling (6)		Ability to carry heavier loads (17)	
Increased physical activity (6)		Lower environmental impact (9)	
Increased confidence riding in traffic compared to conventional cycling (5)		Ability to combat weather conditions compared to conventional cycling; less impact from wind (7)	
Increased feelings of autonomy over travel in comparison to public transport or car (2)		Cost savings (6)	
		Less concern regarding parking or traffic (3)	↓ Least commonly reported
		Ease of use (3)	

environment (see Table 3). Regarding the environment e-bike users felt unsafe riding with motor vehicles due to risk of accidents. In addition, users were concerned about riding alongside conventional cyclists and pedestrians due to potential conflict. Lack of, or poorly maintained, cycling infrastructure exacerbated these safety concerns. For individuals commuting into the city, lack of charging or parking facilities were barriers to riding. The weather, particularly rain, was a commonly reported barrier to e-cycling.

Regarding the e-bike, users felt anxious about the distance they could travel before the battery ran out of charge. Cycling the e-bike without power was not seen as favourable due to the weight of the bike that made it difficult to lift onto cars or public transport and to make repairs. Weight of the e-bike was a greater concern for older adults and women. E-bike users also reported that technical problems were hard to repair themselves or expensive if requiring a mechanic. Maintenance was the most commonly reported barrier to e-cycling for individuals who rode to commute or run errands, while issues with battery life were the greatest concern for recreational cyclists (Haustein and Møller, 2016a). The cost of buying an e-bike and replacing batteries was a barrier to some users, particularly younger adults. Due to the high value of e-bikes users were concerned about theft and therefore carried their e-bike batteries with them when not on the bike.

E-bike users highlighted a general perception of e-bikes being for lazy or overweight individuals and were worried about being judged by others. Younger adults, of working age and who were accustomed to conventional cycling were more likely to report this barrier than older adults. Similarly, the reduced physical activity when e-cycling, compared to conventional cycling, was a barrier for younger individuals.

Some differences in e-cycling barriers were reported across countries. Specifically, in the Netherlands conflict with other cyclists was a barrier to e-cycling, while in the UK the lack of cycling infrastructure and poor parking facilities were commonly reported barriers (Jones et al., 2016).

Prill (2015) reported similar barriers to e-bike use in their workplace e-bike initiative. In addition, if participants had multiple appointments to attend the e-bike was not seen as appropriate. Participants in Malmo, Sweden reported that e-bikes were not well maintained by the organization and batteries were left uncharged (Kroyer and Johansson, 2013). Regarding e-bike share schemes, barriers were similar to those reported for personal e-bike use. In Madrid, uses believed that the geographical coverage of the e-bike share scheme was a barrier to use (Munkacsy and Monzon, 2017). For some users the cost of the schemes were prohibitive to use (Munkacsy and Monzon, 2017; Sustrans, 2013).

3.7.3. *What is known about general attitudes towards e-bikes and e-cycling?*

Overall participants were satisfied with the experience of e-cycling. de Kruijf and colleagues (2019) reported that when e-cycling is perceived as less strenuous it is associated with greater satisfaction, which relates to greater frequency of e-cycling. Dissatisfaction with e-cycling derived from environmental concerns due to poor cycling infrastructure and parking facilities and factors related to the e-bike itself which included poor range and the weight of the e-bike.

Prior to riding an e-bike there was a degree of scepticism associated with e-cycling and a judgement regarding the members of the

Table 3
Barriers to e-cycling, (the number in brackets represents the number of studies reporting that specific barrier).2

Individual	Social	Physical		
		Environmental	E-bike specific	
Less physical effort and activity than conventional cycling (5)	Theft concerns (15)	**Safety concerns** • riding in car traffic (17) • riding with conventional bicycles and pedestrians (6)	**Battery concerns** • Range anxiety (19) • Charging issues: Remembering to charge, not practical, time (5) • Heavy/awkward to carry (3) • Battery life not as long as proposed by manufacturer (2)	Most commonly reported ↑
Getting too sweaty (2)	Social stigma, e-bikes as cheating (8)	**Cycling infrastructure** • Lack of/poor maintenance of cycle lanes (11) • lack of charging stations (2) • lack of parking facilities (3)	**Cost** • E-bike itself (14) • Replacing battery (3)	
Fear of falling (1)	Regulation over where e-bike can be used (3) – North America specific	Weather (especially rain) (13)	**Weight** • Of e-bike (17) • Riding when battery dead (5)	
Unable to ride due to health (1)		Hard to integrate with public transport (2)	Hard and expensive to repair and maintain, technical difficulties (14)	
		Hard to integrate multiple destinations, easier and faster by car (2)	**Design of e-bikes** • Limited load capacity (4) • Too few gears (2) • Gear box issues (1) • Not designed to carry children (1)	↓
		Time constraints, faster by car (2)	Too slow (5)	Least commonly reported
			Uncomfortable (4)	

population for whom e-bikes were designed for. Specifically, e-bikes were perceived as being for older, overweight or lazy adults. However, in one study elderly individuals perceived e-bikes as being for young, active individuals (Cappelle et al., 2003). These perceptions are dynamic with experimental studies reporting that attitudes towards e-bikes become more positive with increased use (Drage, 2012; Edge et al., 2018; Plazier et al., 2017b). Stromberg and colleagues (2016) report that their sample of previous conventional cyclists saw the e-bike as a mode of transportation and not a form of exercise. Similarly, Haustein and Møller (2016a) report that utilitarian e-cyclists appreciate the practically of e-cycling for daily transport and picking up children and shopping. Among e-bike share/rental schemes and workplace initiatives similar attitudes to e-bikes were reported.

4. Discussion

The current review aimed to understand what is known about how electrically assisted bicycles are used, the purpose of their use and their impact on travel behaviour. In addition, the review aimed to provide insight into the motivation for e-cycling, experiences of e-cycling and attitudes towards e-cycling to identify the potential mechanisms that promote or inhibit e-bike use.

4.1. E-cycling and travel behaviour

The evidence suggests that e-bikes increase the total frequency and distance travelled by bicycle and promote longer individual cycle trips, compared to a conventional bicycle. E-bikes appear to substitute for 23–72% of conventional bike journeys and 20%–86% of private cars journeys. While previous research has suggested that conventional bicycles can substitute for private car journeys (Brand et al., 2013; Goodman et al., 2013), the degree of substitution may not be as high as that seen for e-bikes, with Hatfield and Boufous (2016) reporting that recent conventional bicycle trips replaced 33% of car travel in a sample of Australian adults.

The degree to which e-bikes substitute for alternative transport modes largely depends on the primary mode of transport prior to the introduction of the e-bike (Castro et al., 2019; Cairns et al., 2017). Findings of the current review suggest that participants in cities with high levels of cycling often report a shift from conventional cycling, as well as car use, to e-cycling (Astegiano et al., 2017; Haustein and Møller, 2016a; Hendriksen et al., 2008; Lee et al., 2015; Paetz et al., 2012) while in cities or countries with low levels of cycling the primary transport shift is from car to e-bike (Johnson and Rose, 2015; Popovich et al., 2014, MacArthur et al., 2018). As such, interventions should be directed towards areas of high car use to have the most potent impact of population health and road traffic reduction. In many countries, including the UK, the USA, and Australia the majority of journeys are made by car and for relatively short distances (Department for Transport, 2019b; BITRE, 2015a; McGuckin N. and Fucci, 2018). In England, for example, 61% of all journeys are completed by car, of which 68% of these are less than 5 miles in length (Department for Transport, 2019b). These short car journeys have a higher impact on air pollution and carbon dioxide emissions per mile than longer journeys (De Nazelle et al., 2010). Given that most e-bike users travel approximately 7 miles per day, longer than the distance individuals report being willing to travel by conventional bicycle (Pooley et al., 2011), e-cycling could positively impact the environment through the replacement of motorized vehicle use to a greater extent than conventional cycling. For individuals substituting private motorized transport or public transport trips for e-bikes there is a significant increase in weekly energy expenditure, which could positively impact health (Castro et al., 2019).

While e-cycling substitutes for conventional cycling, individuals switching from conventional cycling to e-cycling still accrue enough physical activity to meet the current guidelines for significant health benefits, due to increased frequency and duration of e-cycling (Castro et al., 2019). Furthermore, individuals switching from conventional cycling to e-bikes may be prolonging their cycling engagement as physical limitations or health concerns mean these individuals consider replacing conventional cycling with car journeys. This is commonly reported among older adults (Johnson and Rose, 2015; Leger et al., 2019).

In the workplace, the evidence suggest that e-bikes hold potential to substitute for conventional bicycles or cars, however the decision to adopt an e-bike is highly dependent on work requirements and corporate support of maintenance. Research into the impact of e-bike share or rental schemes is increasing as more e-bikes are integrated into bikeshare systems (Fishman, 2016). Similar to the findings from conventional bike share schemes (Fishman, 2016), e-bikes substitute for a range of transport modes, including walking, public transport and cars, depending on the primary mode of transport in that city. The distance travelled with shared e-bikes is slightly lower than that for private e-bike use. This is not surprising given the bike share systems are introduced in prespecified geographical areas to reduce use of motorized vehicles and enable quick access from one area to another within this location. Therefore, they are bound by the constraints of the prespecified range in which the e-bikes can be used and serve a different purpose to private e-bike use.

4.2. What influences e-cycling?

Individuals engage in e-cycling due to a range of benefits that make e-bikes more appealing than conventional bicycles. These benefits also motivate individuals to purchase an e-bike and serve a specific travel demand, such as carrying more cargo, reducing travel times, or travelling further. Younger adults are largely motivated to ride e-bikes due to the environmental benefits and to reduce outgoings through decreased car use, while older adults are motivated to ride e-bikes due to potential health benefits. As such, future e-bike promotion campaigns should aim to target these populations with different messages, specific to these benefits. In countries with both high and low levels of cycling there was a social stigma associated with e-cycling (Behrendt, 2018; Boland, 2019; Jones et al., 2016; Leger et al., 2019; Dill and Rose, 2012; Paetz et al., 2012). This suggests even in areas with a positive cycling culture such as Portland (USA) and the Netherlands this positive perception may not currently extend to e-bikes which are perceived as being for lazy and/or overweight individuals. Given that social and cultural norms impact levels of cycling (Haustein et al., 2020), it is important that local authorities engage in initiatives to promote e-cycling as a 'normal' mode of transport. This could be achieved through the provision of e-bikes to individuals on trial periods as this review suggests that the negative perceptions of e-cycling often dissipate following engagement with e-cycling (Paetz et al., 2012; Drage, 2012; Edge et al., 2018; Plazier et al., 2017b). This strategy could help to normalise e-cycling and encourage e-bike sales.

The most frequently reported environmental barrier to e-cycling was concern regarding safety specifically when riding in motorized traffic or with vulnerable road users (i.e., pedestrians or conventional cyclists). In the current review there are contradictory results of how the speed associated with e-cycling impacts safety perceptions. Specifically, in some studies participants reported feeling safer riding an e-bike than a conventional bike due to an ability to keep up with traffic and avoid potential accidents (MacArthur and Kobel, 2017; Edge et al., 2018; Dill and Rose, 2012) while in other studies participants reported that the e-bikes speed created dangerous situations, therefore, negatively impacting safety perceptions (Jones et al., 2016; Gordon, 2012; Popovich et al., 2014; Plazier et al., 2018; Haustein and Møller, 2016b). Interestingly, it is the speed associated with e-cycling that contributes to increased excitement and confidence on an e-bike (Haustein and Møller, 2016b, MacArthur et al., 2018).

The speed, and use of infrastructure designed for motorized vehicles as opposed to shared pedestrian paths or cycles ways, has been reported to lead to more conflict between e-bikes and motorized vehicles than conventional bicycles (Dozza and Werneke, 2014; Dozza et al., 2016; Haustein and Møller, 2016b). Interviews with e-bike users in USA showed that e-cyclists were concerned that motor vehicles underestimated the speed of the e-bike due to an inability to distinguish the e-bike from a conventional bike (Popovich et al., 2014), this is supported by video analysis by Dozza et al. (2016) who suggest that while e-bikes look like conventional bicycles their increased speed means drivers have less time to see them or react to them. However, a recent study suggested that after controlling for the amount of cycling (therefore exposure to potential incidents) and age there is no difference in crash risks between conventional bicycles and e-bikes (Schepers et al., 2018).

Interestingly, regular e-bike users are less likely to report traffic incidents than individuals who use an e-bike for a limited period or have less experience (Haustein and Møller, 2016b). This suggests that experience may reduce likelihood of traffic incidents. In the current review e-bike owners tended to report fewer safety concerns than non-users (Simsekoglu and Klöckner, 2019b). Furthermore, countries with low levels of cycling such as Canada, the UK and, USA had more frequent reporting of barriers associated with safety due to poor infrastructure and riding with traffic than countries with high levels of cycling (Gordon, 2012; Haustein and Møller, 2016a; Jones et al., 2016; Leger et al., 2019; MacArthur et al., 2018; Popovich et al., 2014). It is therefore important that potential e-bike users are provided with training on how to safely ride and manoeuvre an e-bike in a low traffic environment to help build confidence and to reduce the likelihood of traffic incidents. Furthermore, local authorities should examine how they can best invest in e-cycling infrastructure to help reduce conflict between different road users.

Additional environmental barriers to e-cycling include poor cycling infrastructure, difficultly integrating bicycles with public transport and limited end of trip facilities. These are similar to the environmental barriers reported for conventional cycling (Heinen et al., 2010) and require collaboration between local authorities and organizations to help improve cycling infrastructure. Barriers specific to the e-bike, including the weight and battery life should be addressed through the provision of suitable e-cycling infrastructure such as charging stations and adapting public transport to incorporate e-bikes. E-bike manufacturers have an important role in streamlining e-bike technology and continuing to reduce the weight of e-bikes.

Overall, e-cycling was more common in men than women, a similar pattern to conventional cycling (Heinen et al., 2010). However, in the current review women were more likely to be e-bike owners than men (Kroesen, 2017). It is possible that women are encouraged to purchase an e-bike due to the anticipated benefits but are more fearful to ride it due to the lack of cycling infrastructure. In countries with high levels of cycling and good cycling infrastructure, such as the Netherlands and Denmark, the mode share of cycling is higher in women than men (Fishman et al., 2015; Haustein et al., 2020; Aldred et al., 2016). This was seen in one experimental study conducted

Table 4
Future research priorities for understanding e-bike use and travel behaviour.

Research priority	Why required
Objective measures of e-bike use and travel behaviour using GPS or smartphone tracking prior to and during e-bike access to quantify the impact of e-bikes on travel behaviour	Current evidence relies primarily on self-report, retrospective measures of travel behaviour
Longitudinal research to examine the causal impact of individual, social and physical determinants associated with e-bike use and travel behaviour	Current evidence provides a qualitative understanding of potential determinants of e-cycling. No studies have examined the individual, social and physical factors directly associated with e-bike use and travel behaviour through quantitative estimates
Research to examine the effect of e-bike availability on travel behaviour by age, sex and socio-economic status	Few studies have examined the impact of demographic outcomes on e-bike use, travel behaviour or the purpose of use
Experimental research to examine effects of e-bike availability on travel behaviour in individuals less familiar with e-cycling	Most of the research to date has been conducted with e-bike owners or those familiar with cycling. Individuals unaccustomed to e-cycling will likely display different patterns of use and possess different attitudes and experiences of e-cycling
Research to examine the potential of e-bikes to serve as company vehicles and replace cars or light goods vehicles for deliveries	Limited research in this area. This is an important area of research as 36% of all car journeys made in England in 2017 were for commuting or business purposes and light commercial vehicles were the faster growing motor vehicle in the UK in the last 25 years
Evaluation of the addition of e-bikes to bike share systems and their impact on alternative transport	Limited research in this area. It is important to ascertain whether the provision of these, more expensive products, is a valuable strategy to increase bike use

in Belgium in which women e-cycled 13% more than men (Cappelle et al., 2003). As such, with the provision of appropriate cycling infrastructure more women may be encouraged to ride an e-bike. E-bike use findings suggest that e-bikes are used more frequently for commuting to work compared to leisure use. However, the distance of commuting journeys is less than during leisure rides (Winslott Hiselius and Svensson, 2017; Haustein and Møller, 2016a). As such, the total distance ridden across a week maybe similar between leisure riders and commuters, but the pattern of use is different which may vary by life stage. For example, Hendriksen (2008) reported that individuals > 65years, mostly leisure riders, rode on average 25.3 km per week, while commuters rode 39.4 km per week. Interestingly, there were no differences in the purpose of e-bike use between countries with high or low levels of cycling. Understanding the purpose for which e-bikes are used is important for local and/or national policy decisions regarding active travel, including e-bike promotion campaigns and for the provision of e-bikes particularly where individuals do not own the e-bikes.

4.3. Research gaps and priorities

The study has identified several gaps in the current literature and provided future research priorities. These are outlined in detail in Table 4. Specifically, research priorities include a) conduct experimental research to examine the impact of adopting e-cycling on travel behaviour in non-cyclists; b) use objective measures to collect data on e-bike use and travel behaviour; c) conduct longitudinal research to examine the causal impact of individual, social and physical factors on e-bike use and travel behaviour; d) examine the extent to which e-bike availability impacts travel behaviour; e) examine the potential for e-bikes to serve as company vehicles and f) evaluate whether e-bike sharing systems impact alternative travel behaviour.

4.4. Implications for policy

The evidence presented suggests that e-cycling has the potential to positively impact the environment, through reduced motorized vehicle use, and individual health, through increased or prolonged cycling. As such, further discussion is required among local and national authorities and researchers to discuss whether the current evidence is strong enough to encourage the promotion of e-cycling as an alternative to motorized transport and to identify what further evidence maybe required to direct and inform policy. Experts should review the psychological factors associated with e-cycling reported here to prioritize schemes that can help to promote e-cycling and reduce motorized vehicle use in areas where motorized vehicle use is currently high.

4.5. Study strengths and limitations

This is the first review to comprehensively explore how e-bikes are used, their purpose of use and impact of travel behaviour and to identify the volume of this evidence. In addition, the review has documented the factors associated with e-cycling and identified key future research priorities. A key strength is the appropriateness of our methods to the research aims, allowing a broad and informative scope of a wide field of literature. In addition, we applied rigorous methods to (e.g. searching, screening, data extractions) and followed the established PRIMSA-ScR checklist.

There are, however, some limitations to consider. Scoping reviews are broad in nature and while they provide an overview of existing literature formal assessment of study quality is not conducted in a scoping review (Arksey and O'malley, 2005; Levac et al., 2010). This can make it difficult to determine the strength of the evidence being reported. In addition, while our search terms were broad it is possible that we missed some relevant articles. The authors decided to exclude studies conducted in China as most e-bikes in China do not require pedalling for assistance to be provided. This exclusion could have meant that some relevant studies were omitted.

Given the heterogeneity of outcomes reported it was not possible to quantitatively synthesize the literature, making comparisons between studies difficult. The authors have attempted to report the results in an objective way and provide sufficient detail for readers to draw conclusions regarding the evidence. Furthermore, when reviewing qualitative research, extraction of common themes was largely guided by the authors' interpretation of the findings and their identified themes. The themes may have been different to those identified by other qualitative researchers.

5. Conclusion

This scoping review identified 76 studies that examined the role of e-cycling on a variety of behavioural and psychological outcomes. The research consistently demonstrated that e-bikes serve to increase cycling frequency and duration and can substitute for motorized transportation particularly short car journeys. With half of all car journeys in the UK being between 1 and 5 miles in length (Department for Transport, 2019a) e-bikes represent a viable sustainable alternative means of transport for a large proportion of car journeys.

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Declaration of competing interest

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

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