CHAPTER ELEVEN

E-bikes—good for public health?

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Introduction

E-bikes represent the fastest-growing segment of the transport system. Combining more bicycle-friendly cities and rapid advances in technology has facilitated the rise of the e-bikes in recent years (MacArthur et al., 2014). In Europe, the sales of e-bikes increased from 588,000 in 2010 to 1,667,000 in 2016 (CONEBI, 2017). In general, e-bikes in European, North American, and Australian context refer to bicycle-style e-bike design (i.e., the bicycle has functional pedals but is assisted with an electric motor) as opposed to scooter-style e-bike design (with no pedals) (Fishman and Cherry, 2016). E-bikes following the regulations made by the European Union are formally known as EPACs (electric pedal-assisted cycle) but are also known as *pedelecs*. The EU regulations mean that the motor assistant is limited to 250 W, and that the motor stops assisting beyond 25 km/h (European Committee for Standardization, 2011). Pedelecs are in most countries legally classified as

Advances in Transportation and Health.
DOI: https://doi.org/10.1016/B978-0-12-819136-1.00011-5

bicycle, as they require pedaling for the electrical assistance to be provided (Fishman and Cherry, 2016). A key difference of the pedelecs compared to the conventional bicycle (CB) is that they can maintain speed, with less physical effort due to the electric-motor support. Following this, pedelecs have been highlighted as an alternative method of active travel that could overcome some of the common barriers to cycle commuting (de Geus and Hendriksen, 2015). In the following, we use the term *e-bike* to denote a bicycle of the pedelec type.

Active transport and health benefits

Increasing cycling as mode of transport is a political goal in several European countries (e.g., Department for Transport, 2017; Norwegian Ministry of Transport and Communications, 2016), in part due to the potential for overall increased physical activity (PA) and subsequent population health benefits (Oja et al., 2011). The mechanisms happening when being physically active (i.e., any bodily movement produced by skeletal muscles, which requires energy expenditure) have both an acute and long-term effect and reduces risk of several noncommunicable diseases (Warburton and Bredin, 2017). Too little PA can have a negative effect on health and increase the risk of diseases such as heart attack, cancer, and diabetes (Bauman, 2004; Warburton and Bredin, 2017). Increasing PA levels as part of our daily travel routine, notably through active transport, can potentially give many individuals an adequate level of PA (Ainsworth et al., 2011; de Geus et al., 2007) and over time, also contribute to greater total PA (Sahlqvist et al., 2012). Active commuting is associated with a lower risk of all-cause mortality and cancer incidence (Celis-Morales et al., 2017).

The health benefits of PA depend on the individual's baseline cardiorespiratory fitness (i.e., weight and maximal O_2 uptake) and the frequency, duration and intensity of the activity performed (Gjerset, 1992). Maximal oxygen uptake (VO_2 max) is the amount of oxygen that the body can utilize in 1 minute. The intensity of PA is categorized in low, moderate and vigorous intensity. It is indicated by the metabolic equivalent of the task (MET), where 1 MET is defined as the energy used at rest (resting metabolism). The exercise intensity should be at least 3 METs (threshold for moderate intensity) in order to promote and maintain health (Haskell et al., 2007). To accrue health benefits The World Health Organization (WHO) (2016) recommends that healthy adults engage in at least 150 minutes of moderate PA or 75 minutes of vigorous PA per week. Behind these recommendations lies an understanding of the physiological mechanisms in which the higher the intensity, the shorter the duration is needed for the same health gain. If an individual has "low" baseline fitness, less duration, frequency and/or intensity is needed for enhanced health effect (Gjerset, 1992; Åstrand and Rodahl, 2003). The greatest gains in health outcomes from active travel are reported in the least active individuals (Oja et al., 2011).

Intensity of physical activity when using e-bikes

As stated previously, it is well established that PA can be accumulated through active travel. As it is through the pedaling that e-bikes may serve to increase PA, we need to understand their potential to promote PA. Is the pedaling sufficiently strenuous to gain clinical benefit?

The intensity of an activity can be measured by means of oxygen uptake, metabolic equivalents, energy expenditure per minute, heart rate, and power output (Åstrand and Rodahl, 2003). Some acute studies have tested physiological parameters across different levels of assistance, from none to maximum electrical power (Simons et al., 2009; Sperlich et al., 2012). However, due to the weight difference, cycling on an e-bike with no assistance does not fairly represent cycling with a CB. Others have therefore investigated the direct comparison between cycling on an e-bike and a CB (e.g., Berntsen et al., 2017; Gojanovic et al., 2011; Theurel et al., 2012). A Swiss study in sedentary subjects ($N = 18$) found intensities of VO_2 max during cycling with an e-bike (high assistance), e-bike (standard), and CB, to be 54.9%, 65.7%, and 72.8%, respectively. The subjects performed all trips at a self-selected pace. For all comparisons, there was a significant difference ($P < .05$) (Gojanovic et al., 2011). In France, Theurel et al. (2012) found average O_2 uptake and HR to be significantly ($P < .05$) lower during e-bike cycling compared to CB ($N = 10$). In this study the bicycles were loaded with 20 kg, in order to simulate the weight of postal mail. A Norwegian randomized crossover study ($N = 8$) found lower exercise intensity (8.5 METs) on the e-bike compared to CB (10.9 METs). In total, 19.9 min was spent in moderate and vigorous activity when using an e-bike, as compared to 23.9 min on a CB. The travel time, when riding an e-bike, was reduced by 35% on hilly routes and 15% on flat routes, resulting in shorter duration of activity (Berntsen et al., 2017). In an American field study ($N = 17$), energy consumption per mile was reported to be 24% lower when pedaling an e-bike, compared with riding a CB, reflecting the shorter travel time. Per minute, there were no statistically significant differences in energy expenditure and ventilation rates between e-bikes and CB (Langford et al., 2017). The differences between e-bikes and CBs are most pronounced in the uphill segment (Berntsen et al., 2017; Gojanovic et al., 2011; Langford et al., 2017), representing a possible adaption by the individuals. When given the choice to self-select pace and intensity, individuals may select a similar physiological intensity across activities regardless of the assistance (CB vs e-bike), thereby resulting in similar physiological outcomes on flat and downhill segments. In hilly terrain, there is less opportunity to adjust effort levels to produce comparable intensity levels. Given the same pace and cycle distance, e-cycling requires a lower level of physical exertion (i.e., expenditure of energy during PA), compared to a CB.

All these findings are summarized in the systematic review by Bourne et al. (2018). Regardless of the difference to CBs, the review shows evidence that cycling with electrical assistance provide PA at least of moderate intensity, for both inactive and active individuals.

Can e-bikes improve cardiorespiratory fitness?

Previous research has shown that cycling on a regular basis (at least three times a week) with a CB positively influences physical fitness (de Geus et al., 2009; Hendriksen et al., 2000; Moller et al., 2011; Oja et al., 2011). As the previous section showed, e-bike users spend less energy than CB users, but they still reach moderate PA intensity. The percentage of peak VO_2 max (i.e., the maximum amount of oxygen that the body can utilize in 1 minute) has been reported to range from 51 to 75 for e-cycling (Bourne et al., 2018). These values exceed the hypothesized minimum of intensity threshold (45% of VO_2 max) required for improvement in cardiorespiratory fitness in healthy adults (Swain and Franklin, 2002).

Acute studies give an indication of the potential of the e-bike to promote PA at an adequate level. The question then arises; can e-bikes improve people's cardiorespiratory fitness?

Several intervention studies have looked at e-cycling in a population over time (De Geus et al., 2013; Höchsmann et al., 2018; Lobben et al., 2018; Peterman et al., 2016), but only a few of these included control groups. A longitudinal study in The Netherlands ($N = 20$) looked at the influence of commuting by e-bike and found that e-bikes may have the potential to improve cardiorespiratory fitness similar to CBs (De Geus et al., 2013). However, the intervention period was too short (6 weeks) to show any significant effect. In a recent Swiss pilot study, physically inactive and overweight participants ($N = 32$) were randomly assigned to ride an e-bike or a CB for a period of 4 weeks. The participants were instructed to use the allocated bicycle for their active commute at a self-selected pace at least three times a week. They found an increase in peak oxygen uptake of 10% [3.6 mL/(kg min)] in the e-bike- and 6% [2.2 mL/(kg min)] in the CB-group. The e-bike users enabled higher speed and elevation gain, potentially outweighing the power assist (Höchsmann et al., 2018). Moreover, a Norwegian pilot study showed an average 7.7% increase in VO_2 max after equipping 25 inactive adults with an e-bike for eight months, an increment being positively associated with cycling distance (Lobben et al., 2018). Accordingly, Peterman et al. (2016), conducting a study in 20 sedentary commuters, found 4 weeks of e-bike commuting to cause significant improvements in 2-hour postoral glucose tolerance test glucose, VO_2 max (8% increment), and maximal power output. These results indicate that for inactive individuals, cardiorespiratory fitness could be improved.

The systematic review by Bourne et al. (2018) points out that future research using rigorous design is needed on long-term health impacts (i.e., changes in cardiorespiratory fitness) of e-cycling.

Substitution effects

From a public health perspective, we are interested in the net volume of health-enhancing PA per week. A key issue in this respect is whether the health effect of increased cycling is canceled out by a reduction in other physical activities—a *substitution effect* (Thomson et al., 2008). The degree to which existing exercise is substituted is of great importance when the cost—benefit account of a given measure or investment is considered. Health benefits account for a large portion of the total benefits for cycling investments; according to a much-cited study as much as 55%—75% of all benefits from cycling infrastructure (Sælensminde, 2004). However, this figure is much debated, and an important part of this debate is the substitution effect. In general, the empirical evidence for substitution is weak (Thomson et al., 2008). Previous estimates of the substitution effect are based on cross-sectional studies (Börjesson and Eliasson, 2012), without sufficient control for population characteristics.

In an attempt to quantify the effect, a Swedish study asking people if increased cycling would lead to a reduction in other forms of exercise found that quite a number of the respondents appeared to have a time budget from which increased time spent traveling would imply decreased time spent on other activities (Börjesson and Eliasson, 2012). Given that the study used people's own estimations concerning alternate activities, the validity of these results is highly questionable. Further, and especially in the case of e-bikes, the fundamental assumption underlying the concept of active mobility is that it does not consume time spent on other activities. In some instances, cycling or walking might take longer time than non-active travel, but in most cases, especially in urban areas, it does not. For illustration, e-bikes are found to be speed competitive with both public transport and private cars (Plazier et al., 2017), meaning that riding an e-bike does not necessarily result in longer travel time than using motorized modes. Still, we cannot rule out that people have a total (physical or psychological) "budget" for PA, and that increased cycling would cause physical or mental fatigue affecting engagement in other activities negatively.

Related to this, it has been suggested that active transport, being more regular and of moderate intensity, has larger public health benefits than the typical infrequent higher intensity activities it replaces (Praznoczy, 2012). Moreover, fitness gains from increased cycling could inspire individuals to be more active in other domains, hence increasing *overall* PA, as has been suggested by studies on health behavior and motivational impacts (Mata et al., 2009; Sniehotta et al., 2005).

Few studies have assessed e-bikes and substitution effects. In a recent study, including data from seven European studies, Castro et al. (2019) found PA (measured as MET minutes per week) from travel-related activities to be similar for e-bike and CB, implying that use of e-bike does not necessarily reduce other PAs. Another study, conducted in Norway, found that for those starting to use an e-bike, other PAs were not significantly affected, that is, indicating no substitution effect (Sundfør and Fyhri, 2017).

Effects on travel behavior

The net volume of PA from starting to use an e-bike depends almost entirely on the transport mode it replaces, and the changes in travel patterns and other PAs (Fyhri and Fearnley, 2015; Sundfør and Fyhri, 2017). A person replacing his regular trip on a CB with an e-bike will have a negative health benefit, given no other adjustment. A person replacing a passive mode of transport (e.g., car) will have a positive health benefit, as the energy expenditure (indicated by METs) is higher when riding an e-bike (Berntsen et al., 2017) compared to when driving a car (Haskell et al., 2007).

Most novel e-bike users are motivated by the power from the engine, leveling out hilly terrain thereby making cycling easier (Fyhri et al., 2017). A Dutch study showed that e-bike users cycled 30 km a week, compared to 18 km a week for conventional cyclists (Fietsberaad, 2013). However, the study did not assess usual cycling distance prior to purchase, making it difficult to draw conclusions regarding changes in travel mode. A Swedish study (Hiselius and Svensson, 2017) appraising self-reported change in transport behavior, indicated that a great proportion of new e-bike trips replaced earlier car journeys. Due to being a retrospective study, asking people to estimate previous behavior, such an estimate is subject to great uncertainty. Many of the e-bike owners have had the e-bike for a long time, up to 3 years.

A British study has undergone research results on the effect of e-bikes on the number of trips traveled by car, and on the number of kilometers traveled (Cairns et al., 2017). The article summarizes findings from European studies on the effect of e-bikes on bicycle trips, replacement of car journeys, etc. In total six studies reported that the proportion of car journeys had been replaced by bicycle journeys as a result of access to an e-bike, with the proportion replaced ranging between 16% and 76%.

Newly, Castro et al. (2019) compared PA levels of e-bike users and CB users (cyclists), as well as across e-bike users grouped after mode substitution, using data from the PASTA project, including over 10,000 participants in seven European cities. PA levels, measured as MET min per week, were found to be similar among e-bike users and cyclists (4463 vs 4085). E-bike users reported significantly longer trip distances for both e-bike (9.4 km) and regular bike trips (8.4 km), compared to users of CB (4.8 km). Also, longer daily travel distances were found for e-bike compared with cyclists for regular bike (8.0 vs 5.3 km per person, per day, respectively). In addition, a decrease of about 200 MET min per week in travel-related activities was revealed for e-bike users who switched from cycling, while those switching from private cars and public transport gained about 550 and 800 MET min per week, respectively. In turn, this indicates that e-bike use could entail substantial increases in PA levels in e-bike users shifting from private car and public transport, while net losses in PA for e-bike users switching from cycling were much less because of increased overall travel distance. However, all of these studies have the same methodology as the before mentioned Swedish study, entailing being retrospective, showing what people remember what they did, or suppose they did before they got the bike.

A scarce number of studies have looked at changes in transport behavior by measuring before and after having access to an e-bike (with a control group). In a Norwegian study, a group of 66 people got access to e-bikes for 2 or 4 weeks. This study showed that the number of cycling trips increased from 0.9 to 1.4 per day, distance cycled increased from 4.8 to 10.3 km, and cycling shares out of all transport increased from 28% to 48%, while a control group ($N=160$) did not have any changes (Fyhri and Fearnley, 2015). In another study, 669 participants that applied for, and received subsidies for e-bike purchase (from the Oslo municipality's subsidy scheme) were measured before, and one month after the purchase of the e-bike. (Fyhri et al., 2016). The results of this study confirmed those of the previous study and found that e-bike owners cycled between 12 and 18 km more each week (compared to a control group) if they replaced a CB with an e-bike, which meant that the initial cycling share was doubled. Those who received e-bike support increased their use of bicycles by 30% at the expense of walking (down 4%), public transport (down 10%), and driving (down 16%). It should be noted that this study was conducted in a Scandinavian context, in a situation where the e-bike was still quite unusual, and the bicycle share is quite low. The effect of e-bikes may be less in a country or a city where many already use bicycles.

Psychological outcomes from riding an e-bike

Previous studies find that cycling to work on a CB elicit more positive affect and enjoyment compared to other modes of travel (Gatersleben and Uzzell, 2007; Rissel et al., 2016). Cycling also happens outdoors and often in green space, and research on exposure to nature shows well-established findings with regard to cognitive benefits, including restoration from mental fatigue (Barton and Pretty, 2010). Research also indicates that there may be a synergetic effect on health from the combination of PA and nature experience (Barton and Pretty, 2010), and cycling to work may have implications for perceived vitality and thereby cognitive performance and work capacity (Calogiuri et al., 2016). Recently, four reasons why cyclists seem to be the most happiest commuters were proposed: (1) greater extent of commuting control and "arrival-time reliability," (2) sensory stimulation reaching enjoyable levels, (3) the mental effects of moderate-intensity PA making one feel better, and (4) more likely for social interaction to occur (Wild and Woodward, 2019).

There are a few studies that have looked at e-bikes and psychological outcomes. A British intervention study by Page and Nilsson (2017) found that people who change their behavior to active commuting by e-bike report more positive affect, better physical health, and more productive organizational behavior, compared with passive commuters. Some studies report enjoyment and positive experiences of the user (Fyhri and Fearnley, 2015; Plazier et al., 2017; Popovich et al., 2014), as well as favorable effects on mental well-being (Jones et al., 2016), and others conclude that due to the decreased amount of effort needed, it might be easier to concentrate (Theurel et al., 2012).

The impact of psychological health arising from riding an e-bike is according to the systematic review by Bourne et al. (2018) inconclusive.

What about accidents?

It has been claimed that an increased use of e-bikes may lead to more traffic accidents (Papoutsi et al., 2014; Schepers et al., 2014; Weber et al., 2014). To be able to discuss this claim, it is important to distinguish among a mere *exposure effect*, an *increased risk*, and differences in *injury severity*.

Regarding the exposure effect, people tend to ride longer when they switch from a CB to an e-bike, as shown in the previous section. Few of the accident studies conducted account well for possible changes in number of e-bikes in traffic and for differences in usage between conventional and electric bicycles. Another limitation with many of the existing studies is that they are based on official injury data or trauma registers. The benefit of this is that the measure of an accident follows a protocol, and hence is less vulnerable to individual assessments. A challenge with these data is that they only cover a small share of all accidents. Underreporting of bicycle accidents is well known (Shinar et al., 2018). In a study from Norway, 10% underreporting of bicycle traffic accidents was found (Bjørnskau, 2005).

A study that accounted for exposure found a small, but significant increase in *accident risk* for e-bikes (Schepers et al., 2014), but in a follow-up study (Schepers et al., 2018), no increased risk of accidents was found. The authors themselves claimed the difference to be methodological, and that the latter result was the most valid. Weiss et al. (2018) found that the risk of a bicycle accident increased with age, but not with bicycle type. Most studies looking at injury severity conclude that there is no difference between e-bikes and CB (Otte et al., 2014; Papoutsi et al., 2014; Weber et al., 2014).

The abovementioned studies lack adequate control with exposure (i.e., distance traveled on the bicycle) to be able to compare accident risk between electric and CBs. And quite importantly, as we have shown, user groups differ, which might influence both accident risk and injury severity.

A Dutch study indicated elevated risk for old women while riding e-bikes (Fietsberaad, 2013). Another study, carried out in Norway ($N = 7752$), combined three data sets to compare conventional and electric bicycles, while at the same time controlling for age, gender, and exposure (Fyhri et al., 2019). The study found an overall risk increase for e-bike users but suggests that all of this risk can be attributed to female cyclists. In other words, women have a higher risk on e-bikes, whereas men do not. Men have a higher total risk. Some, but not all, of this elevated risk can be attributed to experience with the bicycle. Looking at type of injury, e-bikes are not more likely to cause serious accidents than CBs. As opposed to previous studies, no age differences were found.

The health benefit of increased PA accumulated though cycling is found to outweigh the risk of injuries (Andersen et al., 2018; De Hartog et al., 2010). Also, the World Health Organization has developed a tool for Health economic assessment for walking and cycling (HEAT). The tool is based on the best available evidence and estimates the value of reduced mortality that results from specified amounts of PA from cycling (and walking). It also takes into account the health effects from road crashes and air pollution, and effects on carbon emissions (WHO, 2019).

The net public health effects of e-bikes

So, e-bikes, are they good for public health? Well, it depends. It is well established that PA is health enhancing, and that active travel can increase total PA. The e-bike demands lower levels of intensity for the same pace and distance as a CB, due to the assistance of the electrical motor. Depending on fitness level, the intensity when riding an e-bike will differ between inactive and active individuals (i.e., an individual with "high" fitness needs more strain to gain the same intensity level). Still, the e-bike provides PA of *at least* moderate intensity, for both inactive and active individuals.

The net volume of PA from starting to use an e-bike depends almost entirely on the transport mode it replaces, and the changes in travel patterns and other PAs (i.e., substitution effect). Overall, people tend to ride longer and more often when they switch from a CB to an e-bike. The e-bike could entail substantial increases in PA levels for e-bike users switching from a passive mode of transport (i.e., car). For e-bike users switching from previous cycling (CB), there would be net losses in PA (i.e., less effort needed for the same pace and distance), but the overall increased travel time will to a large degree reduce this effect. Other PAs are found not to be significantly affected when starting to use an e-bike, implying that there might not be a substitution effect.

The e-bikes potential to make it "easier" to bicycle motivates novice cyclists and increase the likelihood that these individuals will continue cycling. It could also facilitate use among groups where the CB is no option, such as among elderly and sedentary individuals. For these groups, replacement of trips previously made by CB would be no issue, but their lack of previous cycling experience might be. Most studies looking at injury severity conclude that there is no difference between CBs and e-bikes. For total accident risk, there might be an elevated risk for female e-bike users. Some, but not all, of this can be attributed to experience with the bicycle (novice cyclist). The health benefit of increased PA accumulated through cycling is overall considered as higher than the risk of injuries.

Future trends

In the last 10 years the number of e-bikes in Europe has increased from approximately 600,000 to over 1.7 million. The electric cargo bike, a pedal-assisted e-bike designed and constructed specifically for transporting loads, is an emerging vehicle in many cities these days. Due to the freight aspect, these bicycles might have the potential to compete with the car to a larger degree than regular e-bikes, among both private individuals and companies.

Other devices, becoming more popular these days, are small electrical scooters (classified as bicycles) and boards (e.g., hoverboard). The motor of these are not pedal assisted, and no activity for the rider is needed. Hence, the potential for promoting PA is removed, making them not favorable from a public health perspective.

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