



E-biking substantially reduces the energy costs of physical activity compared with conventional cycling[☆]

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ABSTRACT

Purpose: This study investigated the impact of electric cycling (e-biking) at different levels of electrical assistance compared with conventional cycling on energy expenditure and volume in healthy adults. We hypothesized that greater electrical assistance would lower energy expenditure over a fixed distance in a dose-dependent manner. **Methods:** Ten healthy adults (5 females) completed a randomized crossover trial. After assessment of resting metabolic rate using ventilated-hood indirect calorimetry, participants cycled 3.2 km on three occasions in randomized order: with no, moderate, and maximal electrical assistance. Energy expenditure was assessed using mobile indirect calorimetry. Intensity and volume were expressed as metabolic equivalents of task (METs) and MET-minutes.

Results: Maximal electrical assistance reduced cycling time (8:00 ± 0:18 vs. 10:12 ± 0:41 and 10:36 ± 1:18) and intensity (5.1 ± 1.5 vs. 6.9 ± 1.0 and 7.0 ± 1.3 MET), for moderate and no assistance respectively (P < 0.001). Consequently, both physical activity energy expenditure (37.4 ± 12.3 kcal) and MET-minutes (40.6 ± 11.1) were lower with maximal assistance than with moderate (68.6 ± 13.1 kcal; 70.5 ± 8.4 MET-min) or no assistance (70.7 ± 11.1 kcal; 73.3 ± 7.9 MET-min; P < 0.001). No significant differences were found between moderate and no assistance for any outcome.

Conclusion: While e-biking with maximal assistance is still sufficient to achieve moderate-intensity MET thresholds, it substantially reduces the energy costs of physical activity compared with conventional cycling. If not compensated by longer cycling distances, substituting conventional cycling with e-biking likely diminishes the health benefits of habitual cycling.

1. Introduction

Physical activity is crucial for maintaining good health and well-being. Numerous studies have demonstrated the beneficial effects of regular physical activity, including a reduced risk of chronic diseases such as cardiovascular diseases, type 2 diabetes, and certain types of cancer (Anderson and Durstine, 2019; Kyu et al., 2016). It is well established that the total physical activity volume is a key factor in preventing lifestyle-related diseases (Kyu et al., 2016). Physical activity can be considered as the product of frequency, duration, and intensity (Bull et al., 2020), and is commonly expressed as the total energy expended or the Metabolic Equivalent of a Task (MET)-minutes accumulated over a specified period (e.g. week) (Ainsworth et al., 2011; Craig et al., 2003). Various health organizations have translated the

minimal physical activity volume to confer health benefits into physical activity guidelines which recommend at least 150 min per week of moderate-intensity exercise (3–6 METs) (Bull et al., 2020; Committee PAGA, 2018; Gezondheidsraad. Beweegrichtlijnen, 2017).

Commuting to work or school by bicycle substantially contributes to achieving physical activity guidelines in the Netherlands (BV Dm. Fietsmonitor Jaarrapportage, 2023). This can be attributed to the excellent cycling infrastructure, the relatively short distances between home and work or school, and the convenience and flexibility that cycling offers (BV Dm. Fietsmonitor Jaarrapportage, 2023). In recent years, however, the rapid adoption of electric bikes (e-bikes) has changed the mobility landscape. In 2023, more than 36% of Dutch cyclists reported using an e-bike, corresponding to approximately 4.7 million users, with this proportion continuing to increase (RIVM, 2026).

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E-bikes make cycling more accessible to individuals unable to use a conventional bicycle, enable longer travel distances (Fishman and Cherry, 2016), and can contribute to achieving physical activity guidelines (McVicar et al., 2022). Despite its potential health benefits, there are concerns that electrically assisted cycling could reduce physical activity levels and energy expenditure compared to conventional cycling, particularly for individuals who live near their workplaces or schools (Hoj et al., 2018).

While concerns persist, existing research has primarily emphasized the positive health impacts of electrically assisted cycling. Previous literature indicates that electrically assisted cycling can elicit moderate-intensity exercise and therefore contribute to meeting physical activity guidelines (McVicar et al., 2022; Bourne et al., 2018). However, energy expenditure differs substantially across assistance levels. The largest reductions observed at maximal assistance compared with conventional cycling (Louis et al., 2012; Hansen et al., 2018), whereas reductions at moderate assistance seem less prominent. Nonetheless, some experimental studies suggest a dose-dependent relationship (Alessio et al., 2021; Sperlich et al., 2012). Importantly, several experimental studies have constrained cycling speed (Sperlich et al., 2012; Gojanovic et al., 2011), which may exaggerate differences in exercise intensity between assistance levels and limit ecological validity. As such, current evidence on exercise intensity may not fully reflect real-world e-biking behavior. Another limitation is that many previous studies have only focused on exercise intensity (e.g. MET) without accounting for changes in trip duration (McVicar et al., 2022). This limits conclusions on physical activity volume as a key determinant of health benefits. As electrical assistance increases cycling speed (Berntsen et al., 2017; Langford et al., 2017), trip duration over a fixed distance may decrease, potentially amplifying reductions in overall physical activity volume compared with conventional cycling.

Therefore, the aim of this study was to assess the effects of cycling with moderate and maximal electrically assistance compared with conventional cycling on physical activity energy expenditure and volume in healthy adults. We hypothesized that electrical assistance reduces the energy expenditure of cycling in a dose-dependent fashion.

2. Methods

2.1. Study design and setting

In this randomized crossover trial, participants' energy expenditure during bicycling was assessed during 3 different modes of electric assistance (no, moderate, maximal assistance) in randomized order. The study was conducted at the athletics track of the sport and research center of the Radboud University and HAN University of Applied Sciences in Nijmegen, the Netherlands. The study protocol was reviewed and approved by the Ethical Advisory Committee ECO 533.03/24 of the HAN University of Applied Sciences and found to comply with the standards for the use of human participants as outlined in the latest version of the Helsinki Declaration.

2.2. Participants

Eleven healthy adult individuals (males: $n = 6$; females: $n = 5$) aged 18–55 yr were recruited to participate in this study. Participants were recruited via posters at the HAN University of Applied Sciences in Nijmegen. All participants were recreationally active and had cycling experience. Most had no prior experience with e-bikes but were familiarized with e-biking during the screening procedures. Exclusion criteria were smoking, alcohol abuse (>14 alcoholic consumptions per wk^{-1}), a current injury or an injury over the 3 months before recruitment that could interfere with cycling, diagnosed metabolic disease, and medication known to interfere with energy expenditure (e.g. corticosteroids, beta-blockers). Before inclusion, participants completed a health and exercise history questionnaire to verify eligibility. The participants were

informed about the experimental procedures and potential risks and subsequently provided written consent to participate in the study, in accordance with guidelines set forth by the Netherlands Code of Conduct for Research Integrity (KNAW, 2018).

2.3. Study procedures

2.3.1. Screening and familiarization

During the screening session, basic characteristics including age, stature (cm), and body mass (kg) were recorded. Stature and body mass were measured using a mobile stadiometer and digital scale, respectively (Seca 770 and 213i, Hamburg, Germany). Subsequently, participants were familiarized with the e-bike by covering a distance of 1.2 km on an athletics track at each predefined assistance mode (i.e. no, moderate, and maximal assistance).

2.3.2. Experimental procedure

Participants were instructed to refrain from heavy physical activity in the 24 h before testing. Participants arrived at the exercise laboratory by car or public transport at 08.00 h in an overnight fasted state. Participants rested for a 30 min period in supine position before RMR was assessed over a 30 min period by indirect calorimetry using a ventilated hood (Q-NRG, COSMED, Rome, Italy). Subsequently, participants were equipped with a mobile indirect calorimetry device with face mask (Cortex, Leipzig, Germany) and were subjected to the three experimental bicycling conditions in a randomized order. For each condition, a distance of 3.2 km continuous cycling was completed on a 400 m athletics track at a self-selected, comfortable speed. The conditions were interspersed with 10 min of rest. Heart rate was monitored using a chest strap and wrist monitor (Polar RS800, Kempele, Finland). Directly after completing each condition, the perceived rate of exertion was assessed.

One type of e-bike (Union E-Curb, Dieren, The Netherlands) was used for all conditions. The e-bike was equipped with a motor located in the hub of the front wheel, providing mechanical assistance up to 30 Nm at a maximal assistance speed of 25 km per hour. The e-bike was equipped with 5 incremental assistance modes. Mode 3 and 5 were used for the moderate and maximal assistance conditions, respectively, with the latter supporting a cycling speed up to 25 km per hour. During the 'no assistance' condition, the battery (3 kg) was removed from the e-bike to resemble a conventional bike. For each participant, the saddle height was positioned according to participant's preference. Before each test day, tire pressure was measured and set on 3.5 bar. Participants were instructed to cycle at a self-selected comfortable speed for each condition.

2.4. Outcomes

2.4.1. Measurement of resting metabolic rate

Resting metabolic rate was measured with indirect calorimetry using a ventilated hood system (Q-NRG, COSMED, Rome, Italy). Measurements were conducted under thermoneutral conditions, with an average room temperature of 22.3 ± 0.5 °C, in an awake, comfortable supine position. Equipment was calibrated before each test day according to manufacturer's guidelines. This involved calibrating the gas analyzer using reference gas ($16 \pm 0.05\%$ O₂, $5 \pm 0.05\%$ CO₂, Airgas Specialty Gases, PA, USA) and verifying the calibration against ambient air. A volume calibration was then performed using a standardized 3-L syringe (5530 series, Hans Rudolph, Inc., MO, USA). The resting metabolic rate measurements were conducted over a 30-minute period, during which gaseous exchange samples were continuously collected, and data points were generated every 30 s. Resting metabolic rate was determined as follows: i) the first 5 min of data were discarded; ii) the mean energy expenditure over the subsequent 25 min was used as a measure of RMR; iii) energy expenditure was calculated with the Weir equation (Weir, 1949).

2.4.2. Physical activity energy expenditure

Energy expenditure during physical activity was measured using a mobile indirect calorimetry system (MetaMax, Cortex, Leipzig, Germany). Prior to use, the system was calibrated according to the manufacturer's recommendations after being powered on for at least 20 min. This involved calibrating the gas analyzer using a reference gas (14.97% O₂, 4.96% CO₂) and verifying the calibration against ambient air. A volume calibration was then performed using a standardized 3-L syringe (5530 series, Hans Rudolph, Inc., MO, USA). A respiratory mask (Cortex, Leipzig, Germany) was fitted on the subject and attached to a two-way breathing valve and gas hose, connected to a portable gas analyzer worn in a chest strap. During the cycling bouts, gaseous exchange was sampled breath by breath. Energy expenditure was calculated with the Weir equation (Weir, 1949). Physical activity energy expenditure is expressed as kcal/min and MET. MET-values during physical activity were calculated by dividing physical activity energy expenditure by RMR. MET-minutes were calculated by multiplying the MET value with the physical activity duration expressed in minutes. In addition, the standardized MET according to the 2024 Compendium of Physical Activities (Compendium of Physical Activities, 2024) was calculated by dividing physical activity energy expenditure per min⁻¹ by the standardized RMR per min⁻¹ (body weight in kg⁻¹ · 24/1440).

2.4.3. Perceived exertion

The perceived rate of exertion was assessed directly after completing each cycling condition with the use of the OMNI-scale (Robertson et al., 2003). The OMNI-scale is a visually aided 1–10 rating (1, extremely easy, 10 extremely hard) of perceived exertion (RPE).

2.5. Statistical analysis

The sample size was determined a priori using G*Power, based on assumed mean exercise intensities of approximately 5 MET (maximal assistance), 6 MET (moderate assistance), and 7 MET (no assistance), reflecting a graded reduction in energy expenditure with increasing levels of electrical assistance. These estimates were informed by previous studies and meta-analytic evidence indicating that higher levels of assistance reduce exercise intensity (McVicar et al., 2022). Based on this evidence and the within-subject design, a large effect size was assumed ($f = 0.40$), with a moderate correlation between repeated measures ($r = 0.6$). With $\alpha = 0.05$ and power = 0.80, this resulted in a required sample size of 10 participants.

To test the differences in energy expenditure between the different cycling conditions, normal distribution was first verified by the Shapiro-Wilk test. Data was normally distributed. Subsequently, differences in group means within and between the cycling bouts with regard to energy expenditure, MET-values, MET-minutes, RPE and heart rate were tested with a Repeated Measures Analysis of Variance, with conditions as within-subject factor. All data were analyzed using SPSS (IBM Corporation, Route, Somers, NY, United States) with significance set at $p \leq 0.05$. Results are presented as means with SD.

3. Results

3.1. Participants

Ten out of eleven participants (males: $n = 5$; females: $n = 5$; age 28 ± 10 yr) were included in the final analysis. One participant was excluded from the final analysis due to more than 2 standard deviations in self-selected average cycling speed. The mean body mass, height, and BMI were 71.6 ± 10.4 kg, 1.77 ± 0.08 m and 22.7 ± 2.4 , respectively. Participants' RMR was measured at 1641 ± 278 kcal/day.

3.2. Effect of electrical assistance on basic physical activity outcomes

The duration to cover the 3.2 km distance was shorter in the maximal

assistance condition ($8:00 \pm 0:18$ min:sec $P < 0.001$) compared to the moderate assistance ($10:12 \pm 0:41$ min:sec) and no assistance ($10:36 \pm 1:18$ min:sec) conditions, while no significant difference was observed between the moderate and no assistance conditions ($P = 0.08$). This translates to a cycling speed of 24.0 ± 0.87 km/h in the maximal assistance, 18.9 ± 1.3 km/h in the moderate assistance, and 18.3 ± 2.2 km/h in the no assistance condition.

The mean heart rate was lower during the condition with maximal assistance (106 ± 22 beats per minute [bpm]; $p < 0.001$) compared with moderate (117 ± 16 bpm) and no assistance (122 ± 26 bpm).

Furthermore, the sRPE scores were lower in the maximal assistance condition (1.0 ± 0.5 ; $p < 0.001$) compared with moderate assistance (3.0 ± 1.1) and no assistance (3.5 ± 1.3).

3.3. Energy expenditure during cycling

As shown in Fig. 1a, total energy expenditure during the 3.2 km distance was lower with maximal electrical assistance (46.5 ± 13.0 kcal; $P < 0.001$) compared with moderate electrical assistance (80.2 ± 14.1 kcal) and no electrical assistance (82.7 ± 11.4 kcal), while no significant difference was observed between the no and moderate assistance conditions ($P = 0.191$). This represents a 44% lower total energy expenditure during the maximal electrical assistance condition compared with the condition where no electrical assistance was applied.

After subtracting RMR for the duration of the cycling conditions, the resulting physical activity energy expenditure (Fig. 1b) during the condition with maximal electrical assistance was 37.4 ± 12.3 kcal, which was significantly ($P < 0.001$) lower compared with the trials when moderate electrical (68.6 ± 13.1 kcal) and no electrical assistance (70.7 ± 11.1 kcal) was applied. This represents a 47% reduction of physical activity energy expenditure in the condition with maximal electrical assistance compared with no electrical assistance. No significant difference was observed between the no and moderate assistance conditions ($P = 0.261$).

In line with previous results, the MET values for continuous cycling with maximal assistance (5.1 ± 1.5 MET; $P < 0.001$) were lower compared with moderate assistance (6.9 ± 1.0 MET) and no assistance (7.0 ± 1.3 MET) (Fig. 1c). Similarly, the standardized MET (sMET) values were lower with maximal assistance (4.8 ± 1.3 sMET; $P < 0.001$) compared to moderate assistance (6.4 ± 0.8 sMET) and no assistance (6.4 ± 1.0 sMET). After correcting for the cycling duration per condition, the physical activity volume in the condition with maximal support (40.6 MET-min; $P < 0.001$) was markedly lower compared with no electrical assistance (73.3 ± 7.9), and moderate electrical assistance (70.5 ± 8.4). However, no significant difference was observed between the conditions with moderate electrical assistance and no electrical assistance ($P = 0.183$) (Fig. 1d).

4. Discussion

This study demonstrates that cycling with maximum electrical assistance results in higher cycling speeds and lower intensity compared to cycling without or with moderate assistance. While cycling with maximum electrical assistance still meets the MET-intensity to be classified as moderate-intensity physical activity, the overall physical activity volume, expressed as energy expenditure or MET-minutes, is substantially lower.

4.1. Bicycling characteristics

The time to cover the 3.2 km distance was 25% shorter in the condition with maximum electrical support vs no electrical support. This was associated with cycling speeds of ~ 24 km/h and ~ 18 km/h with maximal electrical support vs no electrical support, respectively. The difference in cycling speed between conditions is consistent with previous studies, which generally reported a 4–5 km/h higher speed with e-

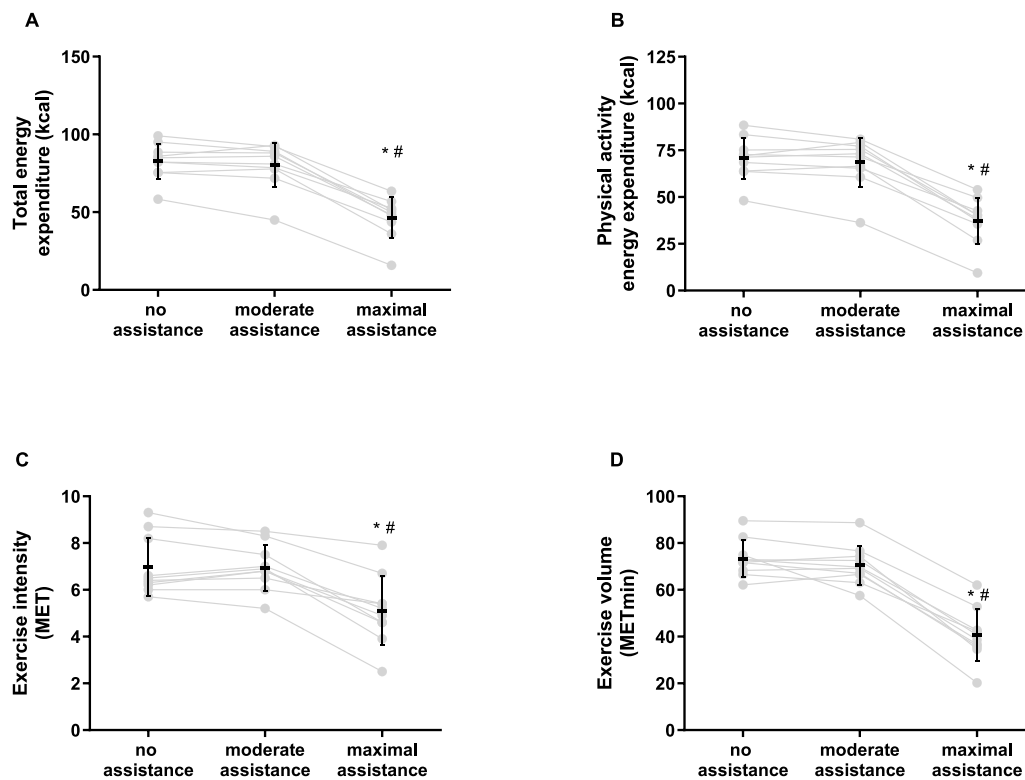


Fig. 1. Energy expenditure, exercise intensity, and exercise volume associated with 3.2 km of cycling under no, moderate, and maximal electrical assistance conditions. Panel A: Total Energy Expenditure. Panel B: Physical Activity Energy Expenditure. Panel C: Exercise intensity expressed as MET values. Panel D: Exercise Volume expressed as MET-minutes. Data are presented as individual values, with black horizontal lines and error bars representing the group mean+SD. * Significantly different ($P < 0.05$) compared with no electrical assistance condition. # Significantly different ($P < 0.05$) compared with moderate electrical assistance condition.

bikes compared with conventional bicycling (Berntsen et al., 2017). Overall, the cycling speed without electrical support was slightly higher in the current study compared with average commuting speed (Vlakveld WP, 2016). This could be attributed to the flat route, the lack of traffic obstacles, and the inclusion of relatively young, healthy individuals.

Besides reducing duration, e-biking with maximum support also markedly lowered the intensity of cycling, reflected by a ~31% lower MET value, as well as substantially lower heart rate (106 ± 22 vs 117 ± 16) and RPE score (1.0 ± 0.5 vs 3.5 ± 1.3). These observations align with previous studies reporting lower MET value (McVicar et al., 2022; Louis et al., 2012; Sperlich et al., 2012), heart rate (Sperlich et al., 2012) and RPE score (Simons et al., 2009) with e-biking compared with conventional cycling. Nevertheless, with a MET value of 5.1 ± 1.5 , maximally assisted e-biking can still be classified as moderate-intensity exercise, which is defined as an intensity of 3–6 MET. This finding corroborates with previous work, reporting MET values of e-biking ranging between 3.8 and 6.5 MET (McVicar et al., 2022; Bourne et al., 2018; Gojanovic et al., 2011). Taken together, our data strengthens the evidence that bicycling with electrical assistance still contributes to achieving physical activity guidelines.

4.2. Physical Activity Volume

When considering both the shorter duration and lower intensity, e-biking with maximal assistance led to a substantially lower physical activity volume. In fact, the physical activity energy expenditure to cover the fixed distance of 3.2 km was ~36 kcal (44%) lower with maximal electrical assistance compared with no electrical assistance. When expressing the volume as MET-minutes, the physical activity volume dropped from 40.6 vs 73.3 MET-min, representing a 45% decline with maximal electrical assistance compared with no electrical

assistance. Our findings are largely in line with those of Berntsen et al (Berntsen et al., 2017), who compared physical activity duration, intensity, and time spent in moderate- and vigorous-intensity physical activity between e-biking and conventional cycling on flat and hilly commuting routes. They observed that e-biking resulted in both shorter trip durations and lower physical activity intensity, thus resulting in lower physical activity volume. This is further supported by Langford et al., who showed that e-biking reduces total energy expenditure primarily due to shorter travel time, despite maintaining moderate-intensity exercise (Langford et al., 2017). The reduction in cycling volume observed in the current study could have a major impact on the weekly physical activity volume. For instance, Dutch bicycle commuters travel, on average, 31.5 km per week (BV Dm. Fietsmonitor Jaarrapportage, 2023; Schulte Nordholt, 2005; Centraal Bureau voor de Statistiek, 2026). Extrapolating the current study’s data to the weekly commuting distance would result in a drop of physical activity volume from 723 MET-min to 434 MET-min, or a reduction in weekly physical activity energy expenditure of ~350 kcal. Such a substantial loss of physical activity volume is clinically relevant, given the dose-response relationship between physical activity volume and various health outcomes, including type 2 diabetes, cardiovascular disease, stroke, and certain cancers such as colon and breast cancer (Anderson and Durstine, 2019; Kyu et al., 2016). Accordingly, a one-to-one substitution of conventional cycling with maximal assisted e-biking erodes the health benefits of habitual bicycling. Cyclists may counterbalance this loss of volume by increasing trip frequency and/or distance. The net health impact of e-biking depends on the counterfactual behavior. Systematic reviews indicate that e-bike use is associated with increased physical activity when replacing motorized transport but may reduce overall activity when substituting conventional cycling (Bourne et al., 2020; Chevance et al., 2025). Observational evidence shows that e-bikes can

substitute both active and passive transport modes, depending on trip purpose and user characteristics (De Haas et al., 2022). These effects are population- and context-specific. In older adults or individuals with reduced physical capacity, e-bikes may facilitate longer distances or higher trip frequency, thereby increasing total physical activity despite lower intensity per trip (Bourne et al., 2018, 2020; Chevance et al., 2025). In contrast, younger and physically fit populations may be more likely to substitute for conventional cycling, potentially reducing physical activity volume (Bourne et al., 2018, 2020; Chevance et al., 2025). This pattern may be more pronounced in countries where cycling already constitutes a substantial share of daily travel (Chevance et al., 2025; De Haas et al., 2022). From an environmental perspective, e-biking may offer broader public health benefits, including reduced traffic-related emissions and a substantially lower environmental impact compared with motorized transport, particularly when replacing car use (Bourne et al., 2020). However, compared with conventional cycling, e-bikes may entail higher environmental impacts due to additional material and energy requirements, particularly related to battery production and electricity use (Fishman and Cherry, 2016). Future work should delineate the populations and contexts in which e-bike use enhances or diminishes overall physical activity volume, environmental impact, and downstream health outcomes.

While we confirmed that e-biking with maximal electrical assistance strongly reduced physical activity volume, no differences were observed between moderate assistance and conventional cycling. In line with these findings, cycling speed, intensity and RPE scores were also unaffected with moderate electrical assistance compared with no assistance. Thus, contrary to our hypothesis, incremental assistance levels did not produce a dose-response. This finding is consistent with some studies showing limited differences between moderate assistance and conventional cycling (Louis et al., 2012; Hansen et al., 2018), whereas other studies report a graded reduction in energy expenditure with increasing levels of electrical assistance (Alessio et al., 2021; Sperlich et al., 2012; Gojanovic et al., 2011). One explanation may relate to contextual factors. For example, Langford et al. demonstrated that the impact of electrical assistance is terrain-dependent, with the largest differences in energy expenditure occurring during uphill cycling and smaller differences on flat and downhill sections (Langford et al., 2017). As our study was conducted on flat terrain, this may partly explain the absence of differences. A second explanation relates to the type of motor used. The e-bike was equipped with a front-hub motor, which provides assistance based on wheel speed. Support during moderate assistance ceased at 18–19 km/h. Considering that participants cycled at similar speeds without assistance, the additional support may have been minimal at their self-selected pace. This is supported by the lack of difference in sRPE, suggesting that participants hardly perceived additional assistance. Effects may have been more pronounced in populations with lower cycling speeds, such as older individuals. Furthermore, mid-drive motors, which are typically torque-based, provide assistance in response to pedaling force and may offer more consistent support across a wider range of cycling conditions. Future research should therefore examine the effects of electrical assistance using different types of e-bikes, particularly comparing hub-driven and mid-drive systems, as well as across diverse populations.

4.3. Limitations and strengths

There are some strengths and limitations to consider in the current study. A key strength is the use of individual resting metabolic rate measurements, enabling more accurate estimation of net physical activity energy expenditure and true MET values. The continuous cycling protocol allowed participants to cycle at a self-selected speed while minimizing environmental variability (e.g., wind, traffic, incline). Despite this controlled setting, a clear reduction in total physical activity volume was observed. In real-world conditions, which involve frequent stop-and-go movements and repeated accelerations, the effects of

electrical assistance are likely to be more pronounced due to higher transient power demands. As such, future research in more ecologically valid settings may reveal even greater differences in total energy expenditure and physical activity volume between e-biking and conventional cycling. Another limitation is the relatively small sample size, although it was determined a priori and the crossover design increased statistical power. While clear differences were observed between maximal and no assistance, no differences were found between moderate and no assistance. While a larger sample size may have detected small, but statistically significant differences between moderate and no assistance, the differences would have been of limited practical relevance. A potential limitation of this study is that the no-assistance condition was performed using the same e-bike with the battery removed. This may have slightly overestimated energy expenditure differences due to the higher weight compared with a conventional bicycle. However, this effect is likely negligible during steady-state cycling on flat terrain. Moreover, using the same bicycle ensured identical geometry and minimized biomechanical variability. Finally, the current findings reflect e-biking with a standard front-hub motor e-bike. It is conceivable that other types, such as fatbikes, speed pedelecs, or mid-motor e-bikes, would produce more pronounced differences in energy expenditure compared with conventional bicycles.

In conclusion, e-biking with maximal electrical assistance can still be considered a form of moderate-intensity physical activity, yet it substantially reduces the physiological demands compared with conventional cycling. For a given route, this results in a markedly lower accumulation of physical activity. Unless compensated for longer cycling distances or additional exercise, replacing conventional cycling with maximally assisted e-biking will therefore reduce overall activity volume and limit the health benefits normally associated with regular cycling.

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CRedit authorship contribution statement

Jan-Willem van Dijk: Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Audrey Thijssen:** Data curation. **Tjieu Maas:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Nick Johannes Josephus van Schijndel:** Writing – original draft, Methodology, Investigation, Formal analysis.

Competing interests

The authors report no potential conflicts of interest relevant to this article.

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Author responsibilities

The authors' responsibilities were as follows: NvS collected the data, researched the data, and wrote the manuscript. TM designed the study, researched the data, and wrote the manuscript. AT collected the data and contributed to the discussion. JWvD designed the study, contributed to the discussion, and revised and edited the manuscript.

Submission statement

We hereby declare that the work described in this manuscript has not been published previously, except in the form of an abstract or as part of a published lecture or academic thesis. The manuscript is not under consideration for publication elsewhere. All authors approve the submission and publication of this manuscript, and such approval has been granted tacitly or explicitly by the responsible authorities where the work was carried out.

If the manuscript is accepted for publication, it will not be published elsewhere, including electronically and in the same form, in English or in any other language, without the written consent of the copyright holder.

Data availability

Data will be made available on request.

References

- Ainsworth, B.E., Haskell, W.L., Herrmann, S.D., Meckes, N., Bassett Jr., D.R., Tudor-Locke, C., et al., 2011. 2011 compendium of physical activities: a second update of codes and MET values. *Med. Sci. Sports Exerc.* 43 (8), 1575–1581.
- Alessio, H.M., Reiman, T., Kemper, B., von Carlowitz, W., Bailer, A.J., Timmerman, K.L., 2021. Metabolic and cardiovascular responses to a simulated commute on an E-Bike. *Transl. J. Am. Coll. Sports Med.* 6 (2), e000155.
- Anderson, E., Durstine, J.L., 2019. Physical activity, exercise, and chronic diseases: a brief review. *Sports Med. Health Sci.* 1 (1), 3–10.
- Berntsen, S., Malnes, L., Langåker, A., Bere, E., 2017. Physical activity when riding an electric assisted bicycle. *Int. J. Behav. Nutr. Phys. Act.* 14 (1).
- Bourne, J.E., Sauchelli, S., Perry, R., Page, A., Leary, S., England, C., et al., 2018. Health benefits of electrically-assisted cycling: a systematic review. *Int. J. Behav. Nutr. Phys. Act.* 15 (1).
- Bourne, J.E., Cooper, A.R., Kelly, P., Kinnear, F.J., England, C., Leary, S., et al., 2020. The impact of e-cycling on travel behaviour: a scoping review. *J. Transp. & Health* 19, 100910.
- Bull, F.C., Al-Ansari, S.S., Biddle, S., Borodulin, K., Buman, M.P., Cardon, G., et al., 2020. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br. J. Sports Med.* 54 (24), 1451–1462.
- BV Dm. Fietsmonitor Jaarrapportage 2023. Deventer; 2024 5 april 2024. Report No.: 013870.20240314.R5.02.
- Centraal Bureau voor de Statistiek. *Werkzame beroepsbevolking; arbeidsduur 2026* [Available from: (<https://www.cbs.nl/nl-nl/cijfers/detail/85275NED>)].
- Chevance, G., Bourne, J., Foley, L., Green, J., Sundfør, H.B., Fyhri, A., et al., 2025. E-bikes and travel behaviour change: systematic review of experimental studies with meta-analyses. *Transp. Rev.* 45 (3), 433–454.
- Committee PAGA, 2018. *Physical Activity Guidelines Advisory Committee Scientific Report, 2018*. U.S. Department of Health and Human Services, Washington, DC.
- Compendium of Physical Activities. 2024 Compendium of Physical Activities 2024 [Available from: (<https://pacompendium.com/>)].
- Craig, C.L., Marshall, A.L., Sjöström, M., Bauman, A.E., Booth, M.L., Ainsworth, B.E., et al., 2003. International physical activity questionnaire: 12-country reliability and validity. *Med. Sci. Sports Exerc.* 35 (8), 1381–1395.
- De Haas, M., Kroesen, M., Chorus, C., Hoogendoorn-Lanser, S., Hoogendoorn, S., 2022. E-bike user groups and substitution effects: evidence from longitudinal travel data in the Netherlands. *Transportation* 49 (3), 815–840.
- Fishman, E., Cherry, C., 2016. E-bikes in the mainstream: reviewing a decade of research. *Transp. Rev.* 36 (1), 72–91.
- Gezondheidsraad. *Beweegrichtlijnen 2017*. Den Haag: Gezondheidsraad; 2017. Report No.: 2017/08.
- Gojanovic, B., Welker, J., Iglesias, K., Daucourt, C., Gremion, G., 2011. Electric bicycles as a new active transportation modality to promote health. *Med. Sci. Sports Exerc.* 43 (11), 2204–2210.
- Hansen, D., Soors, A., Deluyker, V., Frederix, I., Dendale, P., 2018. Electrical support during outdoor cycling in patients with coronary artery disease: impact on exercise intensity, volume and perception of effort. *Acta Cardiol.* 73 (4), 343–350.
- Hoj, T.H., Bramwell, J.J., Lister, C., Grant, E., Crookston, B.T., Hall, C., et al., 2018. Increasing active transportation through E-bike use: pilot study comparing the health benefits, attitudes, and beliefs surrounding E-bikes and conventional bikes. *JMIR Public Health Surveill.* 4 (4), e10461.
- KNAW. *Netherlands Code of Conduct for Research Integrity*. Den Haag: KNAW; NFU; NWO; TO2 Federation; VSNU; 2018.
- Kyu, H.H., Bachman, V.F., Alexander, L.T., Mumford, J.E., Afshin, A., Estep, K., et al., 2016. Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013. *BMJ* i3857.
- Langford, B.C., Cherry, C.R., Bassett, D.R., Fitzhugh, E.C., Dhakal, N., 2017. Comparing physical activity of pedal-assist electric bikes with walking and conventional bicycles. *J. Transp. & Health* 6, 463–473.
- Louis, J., Brisswalter, J., Morio, C., Barla, C., Temprado, J.J., 2012. The electrically assisted bicycle: an alternative way to promote physical activity. *Am. J. Phys. Med. Rehabil.* 91 (11), 931–940.
- McVicar, J., Keske, M.A., Daryabeygi-Khotbehsara, R., Betik, A.C., Parker, L., Maddison, R., 2022. Systematic review and meta-analysis evaluating the effects electric bikes have on physiological parameters. *Scand. J. Med. & Sci. Sports* 32 (7), 1076–1088.
- RIVM. *Voor- en nadelen van de elektrische fiets*. Bilthoven; 2026 19 januari 2026. Report No.: KN-2025-0120.
- Robertson, R.J., Goss, F.L., Rutkowski, J., Lenz, B., Dixon, C., Timmer, J., et al., 2003. Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Med. & Sci. Sports & Exerc.* 35 (2), 333–341.
- Schulte Nordholt, E., 2005. Hoeveel uren werken we in Nederland? *ESB (Econ. Stat. Ber.)* 90 (4457), 148.
- Simons, M., Van Es, E., Hendriksen, I., 2009. Electrically assisted cycling. *Med. & Sci. Sports & Exerc.* 41 (11), 2097–2102.
- Sperlich, B., Zinner, C., Hébert-Losier, K., Born, D.-P., Holmberg, H.-C., 2012. Biomechanical, cardiorespiratory, metabolic and perceived responses to electrically assisted cycling. *Eur. J. Appl. Physiol.* 112 (12), 4015–4025.
- Vlakveld WP. *Elektrische fietsen en speed-pedelecs*. Den Haag: SWOV (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid); 2016. Report No.: R-2016-7.
- Weir, J.B.D.V., 1949. New methods for calculating metabolic rate with special reference to protein metabolism. *J. Physiol.* 109 (1-2), 1–9.