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The effects of subsidising e-bikes on mode share and physical activity - A natural experiment

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ABSTRACT

Introduction: The promotion of increased cycling is a political goal in numerous countries due to its environmental and public health benefits. Initiatives to stimulate e-bike use, like subsidies, may be a relevant strategy. However, understanding of the effects of these subsidies remains limited. In the present study our aim was to investigate the short-term effects of subsidising e-bike purchases on mode share distribution, physical activity derived from daily travel, and overall levels of physical activity.
Methods: We used the 2020-subvention program in Oslo, Norway, as a natural experiment, employing a pre-post randomised group design. The trial group (N = 194) and control group (N = 2174) participated in a survey at two time points (in April and September 2021), which included a one-day travel diary and questions about physical activity over the previous week.
Results: Our findings revealed a significant 12.6 [7.2, 18.0] percentage point increase in bicycle mode share, followed by a decrease in the share of car and public transport usage of 10.1 [-15.9, −2.5] and 7.1 [-11.8, −2.4] percentage points. In terms of physical activity generated from daily travel, we observed a greater increase in e-cycling compared to the decrease in conventional cycling and walking, resulting in an overall rise in active transport. However, despite these findings, we did not detect a significant increase in overall physical activity resulting from this increased active mobility.
Conclusion: Initiatives such as subsidies for e-bikes may align with both environmental and public health goals, as the subvention led to an increase in the bicycle mode share and an overall rise in active transport. However, to assess the impact on overall physical activity, additional research utilising more precise measurements is needed.

1. Introduction

The promotion of increased cycling is a political goal in numerous countries due to its environmental and public health benefits (Department for Transport, 2017; Oja et al., 2011). Initiatives to stimulate e-bike use, like subsidies, may be a relevant strategy as the electrical motor assistance reduce common barriers to cycling (de Geus and Hendriksen, 2015). Additionally, financial initiatives are found to be a strong predictor for the intention to purchase e-bikes (Djokic et al., 2023). Various iterations of support programs have been implemented in several cities in Norway (e.g. Sundfør and Fyhri, 2022; Vigdel, 2020) and other European countries (European

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Cyclist Federation, 2022). However, to date, only one study has so far evaluated their immediate effects on travel behaviour (Sundfør and Fyhri, 2022).

In a European context, e-bikes refer to the pedelec type, where pedalling is necessary to activate the electrical motor assistance (limited to 25 km/h and 250 W) (European Committee for Standardization, 2023). Previous research has shown that gaining access to an e-bike increases the bicycle mode share (e.g. Fyhri and Fearnley, 2015; Fyhri and Sundfør, 2020; Sun et al., 2020; Söderberg et al., 2021). In a scoping review, Bourne et al. (2020) suggested that the adoption of e-cycling largely substituted conventional cycling and private car journeys. The extent of mode substitution depended on the primary mode of transportation prior to acquiring an e-bike. When considering environmental objectives, the primary goal is to increase the overall bicycle usage - preferably at the expense of motor vehicles. In this context, whether the bicycle is electric or conventional are of less importance (Blondel et al., 2011).

However, the type of bicycle is relevant when addressing the public health perspective, as e-bikes require lower levels of intensity to cover the same duration and distance (Berntsen et al., 2017; McVicar et al., 2022). In accordance with international guidelines for physical activities (Bull et al., 2020) the focus is on promoting physical activity as part of everyday life, particularly encouraging people to choose active transport over passive modes such as cars. Numerous studies have compared the difference in physical exertion between e-cycling and conventional cycling (e.g. Berntsen et al., 2017; Gojanovic et al., 2011; Langford et al., 2017). In a recent meta-analysis, McVicar et al. (2022) reported that e-cycling required 17% less intensity, compared to conventional cycling and was associated with an increase in physiological responses equivalent to moderate intensity physical activity.

Sven et al. (2022) found in their research, that e-bikes might be linked to a decreased likelihood of achieving the recommended physical activity levels, attributed to shorter duration and a less cardiovascular strain during rides. However, Riiser et al. (2022) conducted a systematic review indicating that e-cycling could enhance health. They emphasise, though, the necessity for more in-depth longitudinal studies and specifically randomised trials to explore the health effects of e-cycling more thoroughly.

When evaluating transport interventions, it is important to consider non-transport physical activity as well, as there is potential of behavioural adaption in physical activity (Brondeel et al., 2019). If an individual becomes less active in other areas after starting to use an e-bike for transport, this may indicate a balancing effect consistent with the ActivityStat or Compensation hypothesis. This hypothesis suggests that our biology ensure a consistent level of physical activity (PA) and energy use over a certain time period (Gomersall et al., 2013; Rowland, 1998). According to this, a given level of transport-related PA at one time-point will be compensated with a reduction in other activities at a later time-point. Alternatively, should e-bike usage lead to overall heightened activity, without a decrease in other activities, this supports the Generalization hypothesis, suggesting that being more active in one area, like transportation, prompts a corresponding increase in other domains (Carlson et al., 2017). If e-bike usage does not affect other physical activities, keeping them steady, then the Independence hypothesis applies, indicating that activity in one area does not necessarily change activity levels in other areas (Melanson, 2017). The latter hypothesis is often implicitly assumed in studies that exclusively evaluate the impact of interventions on active transport behaviour.

The literature on active transport and overall physical activity presents varied results. Sundfør and Fyhri (2017) investigated the increase in overall physical activity-minutes between e-bike users and non-users and found no evidence of a substitution or compensatory effect, in line with the Independence hypothesis. However, this study did not acknowledge the difference in physical exertion between e-cycling and c-cycling. In another study, they observed similar levels of physical activity from travel-related activities among e-bikers and conventional cyclists, but lower levels of recreational physical activity among e-bikers compared to conventional cyclists (Castro et al., 2019). Foley et al. (2015) and Sahlqvist et al. (2012) found results supporting the Generalization Hypothesis, that changes in active commuting were associated with commensurate changes in total self-reported physical activity. On the contrary, Brondeel et al. (2019) found that transport-related physical activity was partially compensated.

Overall, existing evidence indicates that in adults, increased active transport does not lead to a significant decrease in physical activity in other domains. This trend seems consistent across most adult age groups, with older populations potentially being an exception (Wanjau et al., 2023). However, only a few studies have specifically focused on e-bikes and measurement difficulties preclude a definitive answer.

Despite numerous e-bike subvention initiatives, there is a shortage of research examining their impact on key goals such as mode substitution (more cycling) and enhancing physical activity level. Sundfør and Fyhri (2022) reported that a subvention for e-bikes resulted in a modal shift towards more cycling and an increase in physical activity related to cycling. However, they used distance as a proxy for the effect on public health and only reported transport-related PA. This highlights the need for more comprehensive studies that examine the association between subsidies and public health, incorporating measurements of time, to assess the difference in time spent cycling. Additionally, it is crucial to clearly differentiate the physiological differences between cycling on an e-bike and a conventional bicycle, as well as explore potential compensation of other physical activities, both during active transport and leisure-time physical activity. Obtaining more comprehensive insights into the effects of e-bikes subsidies on mode share and physical activity requires an improved study design compared to previous studies, preferably a randomised controlled study, with special attention to the direction of causality.

1.1. Aim and hypothesis

The main aim of the study was to explore the workings of a subvention for e-bikes within a population. Based on existing literature and the identified research gaps we formulated the research question: What are the short-time effects of subsidising e-bike purchase on everyday cycling and physical activity?.

We had three defined hypotheses derived from this:

1. Subsidising e-bikes will lead to an increase in the bicycle mode share for trips below 50 km
2. Subsidising e-bikes will lead to an increase in MET-minutes of physical activity derived from daily active travel
3. Subsidising e-bikes will lead an increase in overall MET-minutes of physical activity

1.2. Study context

Oslo City Council has previously conducted two rounds of e-bike subsidies. These occurred in 2016 (see Sundfør and Fyhri, 2022) and 2018 (which was not evaluated). The context of this study is the third round, that was initiated in 2020. Under this scheme, all Oslo residents (aged 18 and above) were eligible to apply for a subvention, which covered up to 50% of the cost, with a maximum of 5000 NOK, from the Oslo City Council. Of the 14 581 applicants, 1100 received a subvention. To obtain the actual subvention, applicants were required to submit a receipt after purchasing the e-bike.

2. Material and methods

2.1. Procedure and design

The study was conducted as a pre-post randomised controlled study with two waves of measurements. A total of 14 581 applied for a subvention in the beginning of December 2020 (7th to 11th). To apply one had to reside in Oslo and be over the age of 18. E-bike ownership before the intervention did not disqualify participant. The randomisation was conducted by stratifying by city district, so that 700 e-bike subsidies went to applicants from five districts located east of Oslo. The remaining 400 subventions went to applicants

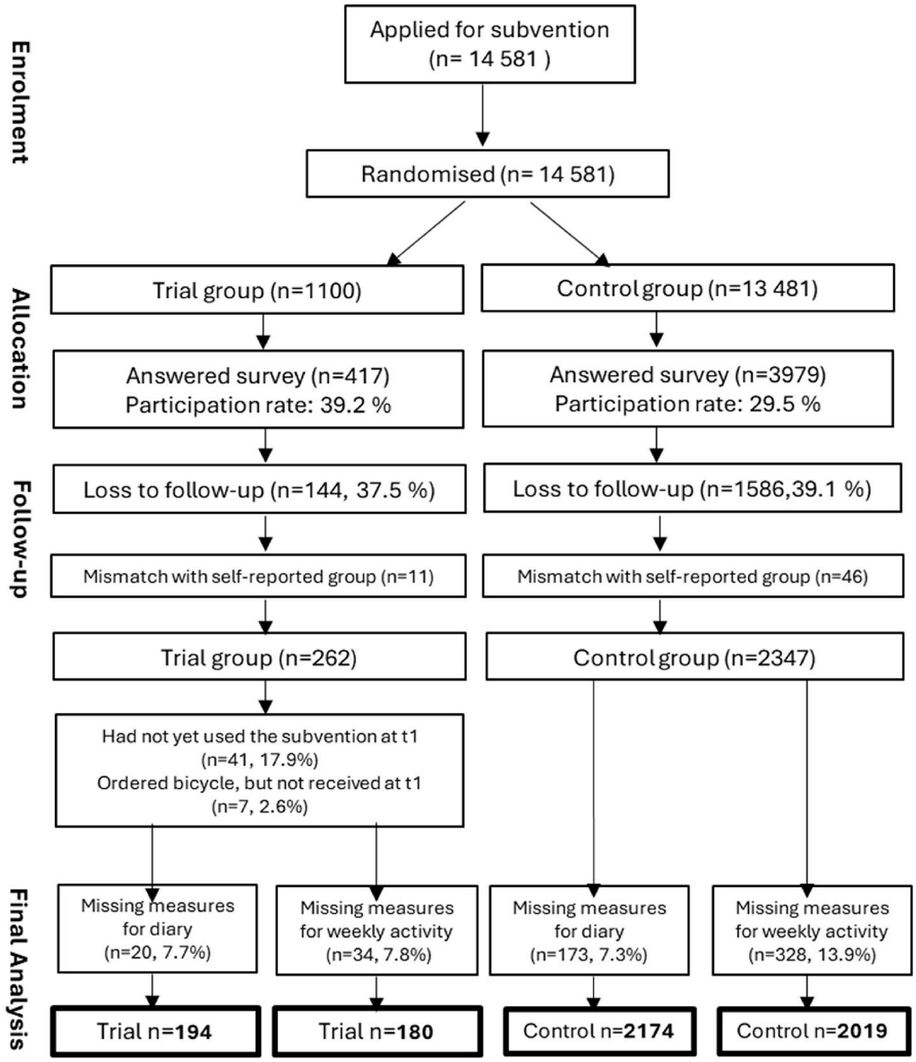

Fig. 1. Flow chart of participant enrolment, randomised group allocation and final analyses.

from the rest of the city (10 districts). The City Council administrated the process. Notifications regarding the outcome were sent promptly and by no later than December 22nd, 2020. There was no system for transfer of subsidies. A web-based baseline survey was distributed in April (22nd) 2021, with a follow-up in September (15th) 2021, to all who responded at baseline (N = 4396). We received information about group affiliation (trial/control) from Oslo City council, which we used for allocating participants into correct trial and control groups in the analysis. The procedure from enrolment to final analysis is presented in Fig. 1.

After excluding those not eligible due to various reasons – such as a discrepancy between self-reported group allocation and the list provided by the City Council, failure to meet the inclusion criteria (i.e., had not purchased e-bike at follow-up) or providing not credible data (i.e., outliers responses) – there were for the final analysis on mode share and physical activity resulting from active travel included 194 in the trial group and 2174 in the control group (Hypotheses 1 and 2). For analysis of overall physical activity, there were 180 in the trial group and 2019 in the control group (Hypothesis 3). In the control group, 373 (17.1 per cent) had bought e-bike within the trial period. In the trial group, 76 had started using the subsidised e-bike before completing the baseline survey.

2.2. Measures and data preparation

2.2.1. Survey measures

The questionnaires included a one-day travel diary that captured distance travelled per mode and overall distance (i.e., mode share). The surveys were distributed between Thursday and Saturday, targeting the preceding weekday for travel diary entries. A trip was defined as travel between two places associated with a trip purpose. If the participants had travelled outside their home on the preceding day, subsequent questions about travel mode, purpose, distance, and duration were presented and required answers. There was a maximum of eight trips. The travel mode could be on foot or by conventional bike, e-bike, public transport, or private car. To classify the purpose of trips, ten categories were used (i.e., to/from work, work trip, journey home, errand, accompanying journey, leisure trip or visit, exercise (to a facility), longer journey, other purpose).The travel diary has been used in previous studies (Fyhri and Sundfør, 2020; Sundfør and Fyhri, 2022).

We measured weekly bicycle use, walking, and other leisure time activities using the following phrasing for all items: *Try to estimate the total time (hours/minutes) you have spent on (e-cycling, c-cycling, walking, moderate physical activity, vigorous physical activity) in the last seven days.* As an introduction to each activity, they were also asked to report the number of days and reminded not to include previously reported activities. For cycling and walking, the respondents were asked to distinguish between transport and leisure time objectives. The self-reported activity measures are a modified version of the Transport and Physical Activity Questionnaire (TPAQ) which has been found to have reliability and validity comparable to those of similar existing questionnaires (Adams et al., 2014; Lee et al., 2011).

The trial group was asked if (and when) they had bought the subsidised e-bike, while the control group was asked whether they had purchased an e-bike after the end of April 2021. Relevant socio-demographic variables were collected to compare the groups, including age, gender, and previous cycling experience.

2.2.2. Data preparation

Data was prepared and analysed using SPSS Statistics 22 and R 4.3.0. The analysis compares values at follow-up between groups, with baseline values serving as a covariate (Between-groups ANCOVA). For the travel diary, we only included trips under 50 km, as we are interested in journeys that could potentially be replaced by bicycle use. We used the distance travelled per mode per day for an individual as the unit of analysis. To calculate cycling mode shares, we combined distances travelled by e-bike and c-bike and divided it by the total distance travelled. To compare pre-post values, those who had not travelled were assigned zero for both mode of transport and total distance.

For the activity measurements, we excluded reported minutes exceeding 1260, based on the International Physical Activty Questionaire (IPAQ)-methodology which caps reported activity at 3 h (180 min) per day. Following this, a maximum of 21 h (3 h per day over 7 days) is allowed per activity category. Instead of truncating, we removed reports exceeding this limit across all activities to avoid extreme values (Adams et al., 2014; IPAQ, 2005).

Metabolic equivalent of task (MET) is a physiological measure that represents a method for expressing the intensity of physical activities as multiples of the resting metabolic rate (i.e., 1 MET) (Byrne et al., 2005). To calculate the MET-minutes in daily travels and overall physical activity, we multiplied the reported minutes by a given MET-value for each transport mode or activity. The MET-values used in the analyses are listed in Table 1.

The MET estimates for walking, public transport, car, as well as vigorous and moderate intensity physical activity were selected

Table 1
Selected MET-values for different modes of transport.

Transport mode and type of physical activity	MET
Walking (4–5 km/h)	3.0
C-bike	6.8
E-bike	5.6
Public transport	1.3
Car	1.3
Physical activity, moderate	4.0
Physical activity, vigorous	7.0

based on the Compendium of Physical Activities (Ainsworth et al., 2011b,a). Due to the range within vigorous and moderate activities, MET-values were chosen based on the threshold value, pluss one. The MET-value of 6.8 for a conventional bike (c-bike) and 5.6 for an e-bike (a factor of 0.83) is based on the study by McVicar et al. (2022). Those who had not travelled were assigned zero for both mode of transport or activity, and total MET-minutes. The MET-value are multiplied by reported minutes of each activity, accordingly. For those who began using the subsidised e-bike prior to completing the baseline survey ($n = 76$), we imputed their baseline values on relevant outcome variables using means values. The mean imputation was based on four age categories and gender (reported in the appendix, Table A.11).

In our study design, observations are independently and randomly obtained from the population. A scatterplot of observed values of group and outcome variables indicates linearity between variables. The data does not meet the homoscedasticity and normal distribution assumption due to a high number of zeros in the dataset. Still, given the relatively large sample size, we decided that data were suitable for analyses, but that results must be interpreted with caution.

3. Results

In the present study we aimed to assess the effects of subsidising e-bikes purchase on mode share distribution, physical activity resulting from daily travel, and overall levels of physical activity.

3.1. Characteristics of participants

The characteristics of the participants in the trial and control group at baseline and at follow-up are presented in Table 2.

The groups were relatively comparable at baseline. However, the control group had a higher representation of individuals with higher education and older age. These similarities suggest that the random selection procedure was successful. Still, it's worth noting that we only retained 40% of the original sample at baseline. Comparing the groups from baseline to follow-up, the composition of the trial group had minor changes, with a slight increase in male participants, more individuals employed, and a higher level of sedentary work and higher education. In the final analyses, the trial and control groups are not significantly different, except for more individuals in the control group reporting having travelled (yesterday) at follow-up.

3.2. Subsidies effect on mode share

The mean adjusted distance per mode for the trial and control group at follow-up and the difference between the groups are presented in Table 3. The numbers are adjusted for baseline values (reported in Table A. 1).

There was a significantly higher amount of distance travelled by e-bike in the trial group compared to the control group, and a significant reduction in c-bike, public transport and walking. Overall, the bicyle distance is 3.1 km higher for the trial group compared to the control group.

The adjusted mean differences in mode share are shown in Fig. 2. The numbers are adjusted for baseline values (reported in Table A. 2). The follow-up values are presented in the appendices (Table A. 3).

There was a significant effect of subvention on bicycle mode share after controlling for baseline values, $F(1,2365) = 18.26$, $p < 0.001$. Parital eta squared (η^2p) was 0.009, which is a small effect size accoding to conventions. As illustrated in Fig. 2, the increase is

Table 2
Characteristics for trial and control group at baseline and follow up. Per cent (and mean value for age).

	t0, baseline		t1, follow-up			
			Final, diary		Final, all activity	
	Trial –	Control	Trial	Control	Trial	Control
% Male	47.7	46.4	51.5	47.8	49.4	46.3
% Employed	74.1	75.5	78.6	76.2	77.2	76.5
% Retired	11.4	9.6	10.8	9.6	9.4	9.1
% Access to e-bike (non-subsidised) before intervention	20.9	23	22.2	23	22.3	21.7
% Sedentary work	61.2	66.1	67.5	67.4	67.7	67.9
% Income >700 000	30.9	34.7	34.5	35.5	32.2	35.2
% Higher education	79.9[a]	84.8[a]	86.1	86.5	83.8	86.4
% Never cycled for transport pre pandemic	–	–	17.5	18.4	18.3	19.9
% Bought e-bike before baseline	32.0[b]	–	41.2	–	42.2	–
% Not bought yet/or received e-bike	–	–	–	–	–	–
% Bought e-bike without subvention	–	–	–	17.1	–	16.2
% Travelled yesterday, at baseline	83.2	85.4	82	85.3	81.7	85.5
% Travelled yesterday, at follow-up	–	–	82.5[a]	87.8[a]	83.8[a]	88.7[a]
mean, age	45.4[a]	47.0[a]	48.7	46.8	47.7	46.0
N	**417**	**3979**	**194**	**2174**	**180**	**2019**

[a] >0.05.
[b] Missing information for n = 11.

Table 3
Adjusted mean distance (kilometres) per mode at follow-up and difference in distance for the trial (n = 194) and control (n = 2174) group. Includes level of significance (p-value) and 95% CI.

	Trial	Control	Difference	Sig.	95 % CI
Walking	1.1	1.6	−0.5	0.037	[-0.9, −0.03]
Bicycle	6.3	3.1	3.1	<.001	[2.1, 4.2]
C-bike	*0.5*	*1.8*	*−1.3*	<.001	[-2.1, −0.6]
E-bike	*5.8*	*1.3*	*4.4*	<.001	[3.7, 5.2]
Public transport	1.5	3.0	−1.4	0.017	[-2.6, −0.3]
Car	5.3	6.9	−1.7	0.108	[-3.7, 0.4]
All transport	14.1	14.6	−0.5	0.069	[-2.3, 1.8]

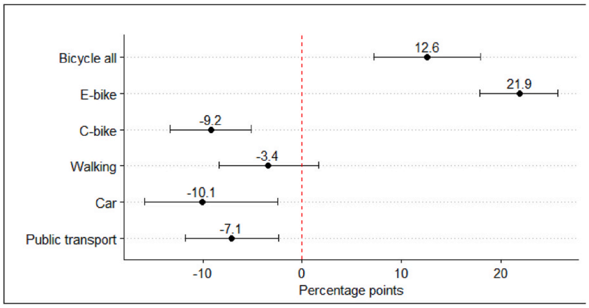

Fig. 2. Adjusted mean difference in mode share between the trial group (n = 194) and control group (n = 2174) at follow-up. Percentage points and 95% CI.

12.6 percentage points [7.2, 18.0] higher in the trial group compared to the control group. The increase in e-bike is 21.9 percentage points [17.9, 25.8] higher for the trial group compared to the control group. For c-bike there is a 9.2 percentage points [−13,3, −5.1] reduction. There was also a significant effect on public transport mode share (F (1,2365) = 7.912, $p < 0.05$, $\eta^2p = 0.004$), with a decline in the trial group of 7.1 percentage points [−11.8, −2.4], compared to the control group. The same held true for the car mode share (F (1,2365) = 4.389, p = 0.036, $\eta^2p = 0.005$), with a decline in the trial group of 10.1 percentage points [−15.9, −2.5] compared to the control group. The reduction of 3.4 percentage points [−8.4, 1.7], in walking is non-significant (F (1, 2365) = 2.67, p = 0.102).

3.3. Subsidies effect on physical activity generated by daily travels

The adjusted mean MET-minutes per transport modes, as well as the merged measures (i.e., bicycle and active transport) are presented in Fig. 3. These figures have been adjusted for baseline values (reported in Table A. 5). The follow-up values are presented in appendices (Table A. 6).

There was a significant effect of the subvention on overall cycling-related physical activity generated from daily travels, after controlling for baseline values, $F(1,2365) = 11.88$, $p < 0.001$, $\eta^2p = 0.006$. As illustrated in Fig. 3, the trial group cyled 32.6 MET-minutes, [15.9, 49.2] more than the control group. The increase in e-cycling was 54.4 MET-minutes [43.4, 65.5] higher in the trial group compared to the control group. There was a parallell decrease of 21.7 MET-minutes [−34.9, −8.4] in c-cycling in the trial group. As for walking, the overall ANCOVA result was significant, $F(1,2365) = 4.442$, $p = 0.035$, $\eta^2p = 0.002$. However, the reduction of 13.4 MET-minutes [−26.9, 0.5] just failed to reach the set level of significance (p = 0.052). The overall ANCOVA results showed a non-

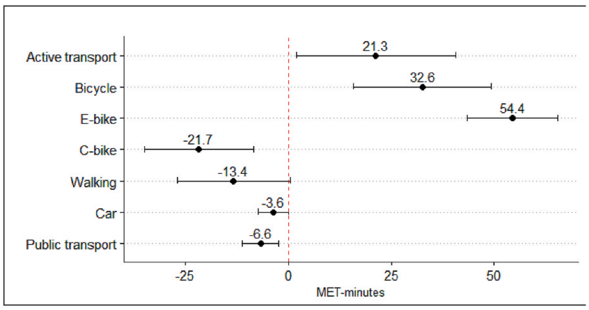

Fig. 3. Adjusted mean difference in MET-minutes for different transport modes between the trial group (n = 194) and control group (n = 2174) at follow-up. 95%CI.

significant effect of the subvention on active transport-related physical activity generated from daily travels, after controlling for baseline values, $F(1,2365) = 3.063$, $p = 0.081$, $\eta^2p = 0.002$. However, the increase in the trial group of 21.3 MET-minutes [2.0, 40.6] was significantly higher ($p = 0.030$) compared to the control group.

We observed a significantly decrease in public transport MET-minutes of 6.6 MET-minutes [−11.1, −2.2] in the trial group compared to the control group ($F(1,2365) = 10.16$, $p = 0.002$, $\eta^2p = 0.004$). For car MET-minutes, the overall ANCOVA results was non-significant $F(1,2365) = 3.424$, $p = 0.064$, $\eta^2p = 0.002$. The decrease of 3.6 MET-minutes [−7.3, 0.1] in the trial group just failed to reach the set level of significance ($p = 0.055$).

3.4. Subsidies effect on overall physical activity

The minutes of physical activity at baseline and follow-up are presented in appendices (Table A. 7 and Table A. 10). Adjusted mean MET-minutes of physical activity related to transport, leisure-time physical activities and merged measures are presented in Fig. 4. These figures have been adjusted for baseline values (Table A. 8).

There was a significant effect of subvention on active transport after controlling for baseline values, $F(1,2196) = 4.69$, $p < 0.030$, $\eta^2p = 0.003$. As illustrated in Fig. 4, the trial group had 173.0 [42.0, 303.0] more active transport MET-minutes than the control group. In terms of overall cycling-related physical activity, including both transport and leisure time objectives, the subvention significantly affected this metric after controlling for baseline values, $F(1,2196) = 6.98$, $p < 0.008$, $\eta^2p = 0.005$. The trial group cycled 289.0 MET-minutes [115.0, 463.0] more than the control group. There was an increase in e-cycling for transport objectives of 405.0 MET-minutes [345.0, 469.0] and for non-transport objectives of 124.0 MET-minutes, [82.7, 167.0] in the trial group compared to the control group. We observed a concurrent reduction in c-cycling for transport objectives of 191.0 MET-minutes [−290.0, −92.4] in the trial group compared to the control group. The decrease in walking for transport [−96.2, 17.8], walking for non-transport [−113.3, 35.1], c-cycling for non-transport [−137.0, 23.7], other moderate PA [−116.0, 70.0] and other vigorous PA [−192.0, 70.0] were non-significant.

Nonetheless, when combining all measures of physical activity to assess the overall difference in MET-minutes, we observed a non-significant effect of the subvention, $F(1,2196) = 0.152$, $p = 0.696$. Meaning that the observed increase of 126.0 MET-minutes [−147.0, 400] in the trail group compared to the control group were non-significant.

4. Discussion

Our study's focus was to explore the workings of an e-bike subvention within a population. Our results illustrate that the subvention program implemented in Oslo in 2020 had a positive impact on cycling behaviour among the intervention group. We observed an increase in both the distance travelled by bike and the share of cycling as mode of transport (Hypothesis 1). Additionally, this increased bike use resulted in higher levels of physical activity from active transportation, measured in MET-minutes (Hypothesis 2). However, we did not find a significant increase in overall physical activity as a result of this increased active mobility (Hypothesis 3).

From an environmental perspective, our findings are consistent with previous research showing an increase in the bicycle mode share (e.g. Bourne et al., 2020; Fyhri and Sundfør, 2020; Söderberg et al., 2021. When comparing our results with those of Sundfør and Fyhri (2022), who reported an increase of 17–22 percentage points in the bicycle mode share, our estimates of 12.6 percentage point were somewhat lower. This discrepancy could be attributed to variations in data collection periods, sample characteristics, or shifts in e-bike purchase trends over time (i.e., it became more mainstream to buy e-bikes in 2020 than in 2016, resulting in a higher proportion of e-bikes in the control group).

From a public health perspective, the rise in e-cycling for daily travel was accompanied by a decrease in conventional cycling and walking. However, there was an overall increase in MET-minutes from active transportation, indicating that the increase in e-cycling outweighed the reduction in walking and c-cycling. This finding is comparable with Castro et al. (2019), who found similar levels of

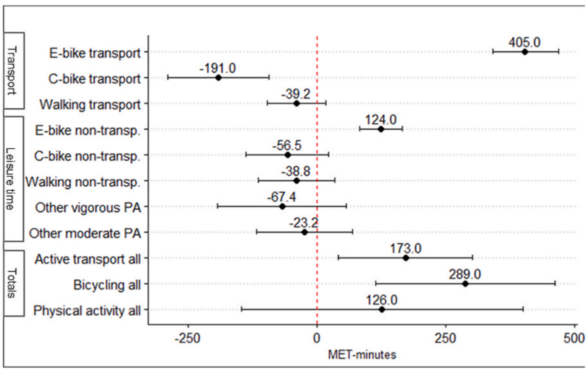

Fig. 4. Adjusted mean MET minutes for transport objectives, leisure-time physical activity and totals for active transport, bicycling and overall physical activity at follow-up in the trial (n = 180) and control group (N = 2019). Included 95% CI.

physical activity from travel-related activities among e-bikers and conventional cyclists. Nevertheless, as we do not have control over the remaining time use for other activities than transport, we cannot present a comprehensive account of physical activity patterns and potential compensatory behaviour throughout the day. For instance, replacing a car journey with an e-bike journey would increase travel time (and the following MET-minutes), while replacing a walking journey with an e-bike might have a different impact.

It is relevant to note that the minutes of physical activity (displayed in Table A. 7 and Table A. 10 in the appendix) reported in our study, are three times higher than the lower recommendations for moderate physical activity minutes per week (150 minutes or 600 MET-minutes) (Bull et al., 2020; Helsedirektoratet, 2022). While these figures may seem high, they are comparable to previous studies using the TPAQ questionnaire (Adams et al., 2014). The reported MET-minutes in our study are only half of those reported by Castro et al. (2019), which could be attributed to higher MET-values. Our chosen MET-values, based on the tracking guide of physical activity (Ainsworth et al., 2011b) and the study by McVicar et al. (2022), could to some degree influence the results. However, as we compare changes between groups the overall pattern would most likely be the same.

The significant increase in cycling observed in both daily travel and the overall cycling-related physical activity (including both transport and leisure-time) substantiates previous research findings where distance travelled was used as a proxy for physical activity (Sundfør and Fyhri, 2022). Moreover, to the best of our knowledge, this study is the first to examine changes in active transport relative to other physical activity, following a subvention program. Our results showed a 9.4 % increase in overall PA for the trial group compared to the control group, but the difference isn't substantial enough to rule out chance. This overall increase is primarily due to a rise in cycling, accompanied by a minor decrease in other activities. Since these decreases are not statistically significant, it is unclear whether they represent an actual reduction in line with the Compensation hypothesis (Rowland, 1998), or if other activities have remained stable, as suggested by the Independence hypothesis. In any case, our data do not find support for the Generalization hypothesis, which proposes that an increase in active transport typically results in a corresponding rise in activity levels across other domains (Melanson, 2017). Similar patterns of decrease in other PA were observed by Castro et al. (2019), where they found a higher level (less than 10%, non-significant) of overall physical activity among e-bikers compared to conventional cyclists, followed by lower levels of recreational physical activity. Additionally, Brondeel et al. (2019) found indications of partial compensation in transport-related physical activity. Our findings, combined with previous research, indicates that a form of balancing effect consistent with the Compensation hypothesis, suggesting that some form of substitution may be occurring. However, or data is not sufficient to draw definitive conclusions. Therefore, to fully gasp these dynamics in the context of various hypothesis, further research with more precise measurements is needed.

Within a subvention program we anticipate that not all participants in the trial group will make a purchase, and that some in the control group will buy e-bikes independently. Hence, it is important to note that the follow-up survey was conducted before the end of the trial period, introducing some uncertainties regarding the inclusion of individuals who had not yet purchased an e-bike. These individuals were excluded from the analysis. The decision to exclude them may be questioned, as not all individuals may ultimately make use of the subvention. On one hand, excluding non-users can be justified since there is no cost associated with unused subsidies, and others could potentially benefit. On the other hand, including these individuals (given that the subvention period had ended) would allow us to evaluate the effect of the policy, which is understood as granting some people access to subsidies without further administration, hence evaluating the quality of the intervention. Ultimately, our choice to exclude them was deemed appropriate, given that these individuals would with all likelihood become purchasers, even if at a later stage.

In the control group, 17% eventually purchased an e-bike without any subvention. An interesting question in that regard is what the sweet spot for a subvention is. Could the same effect have been achieved for a lower price? From a policy perspective this is a relevant question. We do not have data to test the effect of subvention size on purchase motivation. But we can test if the motivation to use an e-bike is higher among those who made the purchase without a subvention. An ad hoc sensitivity analysis showed no significant difference in cycling share between the trial group (e-bike with subvention) and the control group (e-bike without subvention). In other words, it can be assumed that the size of the subvention will not have any impact on the mode change per individual user resulting from it.

The findings of this study could have implications for policymakers who are considering implementing subventions programs for e-bikes. Such initiatives could have the potential to increase the bicycle mode share while reducing the mode share of public transport and cars. In addition, subsidies may contribute to an overall increase in cycling activity and active transport, and potentially lead to a net volume increase in physical activity. Therefore, we argue that subsidising e-bikes could align with both environmental and public health goals.

4.1. Strengths and limitations

To the best of our knowledge, this study is the first attempt to use a randomised controlled design to evaluate the effect of a subvention program. Unlike previous research, which only used the distance cycled as a measure of physical activity (i.e., Sundfør and Fyhri, 2022), this study stands out by factoring in the reported minutes of activity and adjusting for the difference in physical exertion (measured in METs), between cycling on an e-bike and a conventional bike.

However, despite our random selection procedure, we encountered some discrepancies among those who ultimately participated in the study. Some individuals were lost to follow-up, while others did not meet the defined inclusion criteria (e.g., they had not yet purchased the e-bike). In the end, we only included 18% of all applicants, resulting in a relatively small intervention group. This attrition, or loss to follow-up, could pose a threat to external validity. In other words, the observed effect may not be replicated if the study were to be conducted in a different setting with different types of participants (Matthay and Glymour, 2020). This limitation illustrates the challenges inherent in employing a "natural experiment" as the basis of research, wherein full control over the environment and conditions cannot be exerted.

By randomly assigning applicants to groups, we anticipated that there would be no pre-test differences (Jennings and Cribbie, 2016). In terms of socio-demographics, this expectation was largely accurate as there were no significant differences between the groups. However, it is worth noting that 39% of the trial group had already started using the subsidised e-bike before the baseline measurements, which resulted in some discrepancies between the groups for the outcome variables at baseline. Removing these participants would have compromised the study design. To address this missing data, we employed a mean imputation method based on age and gender (Nicholson et al., 2017). Hence, we were able to use baseline values as covariate in the analysis (Johnson, 2016). A sensitivity analysis revealed a 0.9 percentage point difference in cycling share, suggesting that mean imputation had minimal impact of the results.

Another limitation of this study is the violation of assumptions regarding homoscedasticity and normality of data, which is not uncommon in large-scale studies in the field of transport (e.g. Fyhri and Sundfør, 2020). Therefore, caution should be exercised in interpreting our findings, and replication is needed to confirm them.

Since this study is based on self-reported data, a potential limitation is the presence of recall bias, which can introduce inaccuracies and diminish the relationship between the predictor and outcome variables (Matthay and Glymour, 2020). However, the use of a travel diary for daily data collection may reduce this bias compared to recalling an entire week. However, it should be acknowledged that our conclusions about mode substitution are derived from just two days of data collected over six months, which is a limitation of our study. The majority (over 90%) of responses pertained to weekdays, aligning with our intent to focus on commute-related travel as part of everyday travels. Nonetheless, as the data primarily reflects weekday travel, it offers limited insights into weekend travel patterns.

The Transport Physical Activity Questionnaire (TPAQ) (Adams et al., 2014) used in our study, captures a more detailed account of variations in activities throughout the week by requesting total minutes and distinguishing between transport-related and other physical activities. While this approach provides more granularity, compared to the short- IPAQ (Lee et al., 2011), it may introduce greater recall bias and present challenges during the data cleaning data process. To avoid extreme values, we removed reports exceeding a limit of 1260 min across all activities. This approach, while ensuring data quality, may result in a lower average activity level in our analysis than if these outliers were included. Nevertheless, when adjusting for baseline values and reporting group differences, this is less problematic. Although it may still impact the precision of the magnitude of change over time and future studies should aim to incorporate objectively measured data to overcome this limitation.

One evident limitation of our study design is the timing of the survey distribution. Due to the nature of a natural experiment, we could not fully control whether participants had already purchased an e-bike before completing the baseline survey or had purchased one before completing the follow-up survey. This limitation arose from the limited cycling season in Norway, time constraints and the organisation of the subvention program by the city council. Conducting the follow-up shortly after this deadline would have led to data being collected in January. This would not accurately reflect cycling patterns during the traditional cycling season. Although information on the impact of subsidised e-bikes on winter cycling could have been of interest, it was not the primary focus of our study. Future studies should ideally be conducted in settings where seasonal effects are less influential (long-term effects), allowing for data collection to align with budgetary and organisational constraints typically associated with such policy measures.

5. Conclusions

The findings of this present study indicate that subsidies of e-bikes may lead to an increase in bicycle mode share at the expense of public transport and cars. From a public health perspective, a subvention might have the potential to contribute to this goal by enhancing cycling-related physical activity and overall active transport. Since the outcome of purchasing an e-bike—with or without a subvention—resulted in similar cycling behaviour, we propose that a flat-rate subvention, applicable to all and requiring minimal administration, could be an effective approach. However, additional research utilising more precise measurements is needed to assess their impact on overall physical activity.

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CRediT authorship contribution statement

Hanne Beate Sundfør: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Sveinung Berntsen:** Conceptualization, Methodology, Supervision. **Elling Tufte Bere:** Conceptualization, Methodology, Supervision. **Aslak Fyhri:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Open AI Chat GPT4 in order to improve readability and language. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendices.

Table A. 1
Distance (kilometres) per mode at baseline for trial (N = 194) and control group (N = 2174). Mean and 95% CI.

	Trial		Control		Difference		
	Mean	95% CI	Mean	95% CI	Mean	sig.	95% CI
Walking	2.3	[1.78, 2.89]	2.3	[2.17, 2.50]	−0.002	0.995	[-0.58, 0.58]
Bicycle	1.7	[0.81, 2.65]	2.4	[2.14, 2.69]	−0.67	0.160	[1.65, 0.27]
C-bike	*1.15*	*[0.43, 1.87]*	*1.44*	*[1.22, 1.65]*	*−0.29*	*0.455*	*[-1.04, 0.47]*
E-bike	*0.58*	*[0.00.1.16]*	*0.98*	*[0.81, 1.15]*	*−0.40*	*0.191*	*[0.20, -1.31]*
Public transport	1.03	[0.23, 1.84]	1.40	[1.16, 1.64]	−0.36	0.396	[0.47, −0.85]
Car	6.22	[4.37, 8.07]	5.51	[4.95, 6.06]	0.72	0.466	[-1.21, 2.65]
All transport	11.3	[9.26, 13.4]	11.7	[11.04, 12.3]	−0.34	0.760	[-2.49, 1.82]

Table A. 2
Baseline values for mode share for trial group (n = 194) and control group (n = 2174). Mean and 95% CI.

	Trial		Control		
	Mean	*95% CI*	*Mean*	*95% CI*	*sig.*
Walking	26.7	[20.7, 32.8]	31.6	[29.8, 33.3]	0.133
Bicycle	14.4	[9.59, 19.3]	16.6	[15.1, 18.0]	0.409
C-bike	8.8	[4.86, 12.8]	10.3	[9.11, 11.5]	0.479
E-bike	5.6	[2.47, 8.81]	6.3	[5.34, 7.23]	0.702
Public transport	8.9	[5.42, 12.4]	8.0	[6.95, 9.03]	0.619
Car	37.0	[31.3, 42.7]	25.3	[23.6, 27.1]	<.001

Table A. 3
Adjusted mean values for mode share for trial group (n = 194) and control group (n = 2174) at follow-up. Mean and 95% CI.

	Trial		Control	
	Mean	95% CI	Mean	95% CI
Walking	15.9	[11.0, 20.8]	19.3	[17.8, 20.7]
Bicycle	33.9	[28.7, 39.0]	21.3	[19.7, 22.8]
C-bike	3.3	[-0.7, 7.2]	12.5	[11.3, 13.7]
E-bike	30.6	[26.9, 34.4]	8.8	[7.64, 9.89]
Public transport	8.7	[4.17, 13.2]	15.8	[14.4, 17.1]
Car	18.1	[12.5, 23.7]	28.2	[26.5, 29.9]

Table A. 4
Baseline values for minutes of daily travels for trial group (n = 194) and control group (n = 2174). Mean and 95% CI.

	Trial		Control		
	Mean	95% CI	Mean	95% CI	Sig.
Active transport	29.9	[23.8, 35.9]	34.3	[32.5, 36.1]	0.173
Walking	23.3	[17.8, 28.7]	24.9	[23.2, 26.5]	0.583
Bicycle	6.9	[4.05, 6.69]	6.8	[5.99, 7.68]	0.980
C-bike	*4.3*	*[1.5, 7.03]*	*5.9*	*[5.03, 6.68]*	*0.281*
E-bike	*2.3*	*[0.29, 4.39]*	*3.6*	*[2.94, 4.17]*	*0.264*
Public transport	3.5	[0.94, 6.15]	5.0	[4.22, 5.78]	0.295
Car	11.3	[7.98, 14.6]	10.8	[9.84, 11.8]	0.788
All transport	44.7	[38.0, 51.4]	50.1	[48.1, 52.1]	0.1289

Table A. 5
Baseline MET-minutes for daily travels in the trial (n = 194) and control group (N = 2174). Mean and 95% CI.

	Trial		Control		
	mean	*95% CI*	*mean*	*95% CI*	*Sig.*
Active transport	112.0	[86.3, 138.0]	134.0	[126.8, 142.0]	0.099
Walking	69.8	[53.4, 86.2]	74.6	[69.7, 79.5]	0.583
Bicycle	42.2	[20.5, 63.8]	59.9	[53.4, 66.3]	0.125
C-bike	29.9	[10.2, 47.8]	39.8	[34.2, 45.4]	0.281
E-bike	13.2	[1.59, 24.8]	20.1	[16.6, 23.5]	0.264
Public transport	4.6	[1.2, 8.0]	6.5	[5.5, 7.5]	0.295
Car	14.7	[10.4, 19.0]	14.1	[12.8, 15.4]	0.788
All transport	131.0	[106.0, 156.0]	155.0	[148.0, 163.0]	0.076

Table A. 6
Adjusted MET minutes for daily travels in the trial (n = 194) and control group (N = 2174) at follow-up. Mean and 95% CI.

	Trial		Control	
	mean	*95% CI*	*mean*	*95% CI*
Active transport	115.8	[97.3, 134.0]	94.5	[88.9, 100.0]
Walking	35.9	[23.0, 48.9]	49.3	[45.5, 53.2]
Bicycle	85.0	[69.9, 101.9]	53.3	[48.6, 58.1]
C-bike	11.6	[-1.08, 24.4]	33.3	[29.5, 37.1]
E-bike	74.4	[63.8, 85.1]	20.0	[16.8, 23.2]
Public transport	5.7	[1.41,9.87]	12.3	[11.0, 13.6]
Car	10.4	[6.82, 13.9]	14.0	[12.94, 15.1]
All transport	131.0	[113.0, 149.0]	121.0	[115.0,126.0]

Table A. 7
Baseline minutes of physical activity at baseline for the trial (n = 194) and control group (N = 2174). Mean and 95% CI.

	Trial		*Control*		
	mean	95% CI	mean	95% CI	Sig.
Cycling for transport e-bike	11.0	[1.99, 20.0]	15.5	[12.8, 18.1]	0.351
Cycling for non-transport e-bike	4.7	[-1.32, 10.8]	7.5	[5.67, 9.28]	0.396
Cycling for transport c-bike	24.4	[11.5, 37.3]	30.4	[26.6, 34.3]	0.377
Cycling for non-transport c-bike	14.2	[1.65, 26.8]	24.4	[20.7, 28.2]	0.126
Walking for transport	61.5	[42.7, 80.4]	77.0	[71.4, 82.7]	0.122
Walking for recreation	173.0	[142.0, 204.0]	172.0	[163.0, 181.0]	0.964
Physical activity moderate	87.6	[66.8, 109.3]	89.3	[82.8, 95.8]	0.885
Physical activity vigorous	72.5	[53.3, 91.5]	73.8	[68.1, 79.5]	0.895
Bicycling all	54.3	[31.1, 77.5]	77.8	[70.9, 84.7]	0.057
Active transport	96.9	[72.0, 122.0]	122.9	[115.0, 130.0]	0.049
Physical activity (transport + leisure)	449.0	[392.0, 506.0]	490.0	[479.0, 507.0]	0.174

Table A. 8
Baseline mean MET minutes for active transport and leisure time physical activity in the trial (n = 180) and control group (N = 2019). Mean and 95% CI.

	Trial		Control		
	mean	*95% CI*	*mean*	*95% CI*	*Sig.*
Cycling for transport e-bike	62.0	[11.2, 133.0]	87.2	[72.1, 102.0]	0.351
Cycling for non-transport e-bike	26.8	[-7.45, 61.0]	42.2	[31.98, 52.4]	0.396
Cycling for transport c-bike	166.0	[78.2, 253.0]	207.0	[180.8, 233.0]	0.377
Cycling for non-transport c-bike	96.6	[11.2, 182.0]	166.2	[140.7, 192.0]	0.126
Walking for transport	185.0	[128.0, 241.0]	231.0	[214.0, 248.0]	0.122
Walking for recreation	519.0	[427.0, 611.0]	517.0	[489.0, 544.0]	0.963
Physical activity moderate	351.0	[264.0, 437.0]	357.0	[331.0, 383.0]	0.885
Physical activity vigorous	507.0	[374.0, 640.0]	517.0	[477.0, 556.0]	0.896
Active transport	412.0	[295.0, 530.0]	525.0	[490.0, 560.0]	0.071
Bicycling all	351.0	[200.0, 503.0]	503.0	[457.0, 548.0]	0.060
Physical activity (transport + leisure)	1912.0	[1644.0, 2181.0]	2124.0	[1644.0, 2044.0]	0.139

Table A. 9
MET-minutes for active transport and leisure time physical activity in the trial (n = 180) and control group (N = 2019) at follow-up. Mean and 95% CI.

	Trial	Control

(*continued on next page*)

Table A. 9 (*continued*)

	Trial		Control	
	mean	*95% CI*	*mean*	*95% CI*
	mean	*95% CI*	*mean*	*95% CI*
Cycling for transport e-bike	544.0	[483.0, 605.0]	139.0	[121.0, 157.0]
Cycling for non-transport e-bike	168.2	[127.6, 208.8]	43.7	[31.6, 208.8]
Cycling for transport c-bike	84.4	[-10.4, 179.0]	275.7	[247.4, 304.0]
Cycling for non-transport c-bike	82.9	[6.05, 160.0]	139.4	[116.5, 162.0]
Walking for transport	181.0	[127.0, 236.0]	220.0	[204.0, 237.0]
Walking for recreation	295.0	[225.0, 366.0]	334.0	[313.0, 355.0]
Physical activity moderate	444.0	[325.0, 564.0]	512.0	[476.0, 547.0]
Physical activity vigorous	324.0	[234.0, 413.0]	347.0	[320.0, 374.0]
Active transport	809.0	[684.0, 933.0]	635.0	[598.0, 673.0]
Bicycling all	886.0	[720.0, 1053.0]	597.0	[548.0, 647.0]
Physical activity (transport + leisure)	2137.0	[1874.0, 2399.0]	2010.0	[1932.0, 2088.0]

Table A. 10
Minutes for active transport and leisure time physical activity in the trial (n = 180) and control group (N = 2019) at follow-up. Mean and 95% CI.

	Trial		Control		
	mean	95% CI	mean	95% CI	Sig.
Cycling for transport e-bike	96.5	[857, 107.3]	24.7	[21.4, 27.9]	<.001
Cycling for non-transport e-bike	29.8	[22.6, 36.99]	7.7	[5.6, 9.89]	<.001
Cycling for transport c-bike	12.4	[-1.53, 26.3]	40.5	[36.7, 44.7]	<.001
Cycling for non-transport c-bike	12.2	[0.89, 23.5]	20.5	[17.2, 23.9]	0.167
Walking for transport	60.4	[42.2, 78.6]	73.5	[68.0, 78.9]	0.178
Walking for recreation	98.5	[74.9, 122.0]	111.4	[104.4, 118.0]	0.304
Physical activity moderate	80.9	[56.8, 103.3]	86.7	[80.1, 93.4]	0.625
Physical activity vigorous	63.5	[46.4, 80.5]	73.1	[68.0, 78.2]	0.289
Bicycling all	151.8	[125.8, 178.0]	93.4	[85.6, 101.0]	<.001
Active transport	169.0	[143.0, 194.0]	139.0	[131.0, 146.0]	0.027
Physical activity (transport + leisure)	458.0	[404.0, 511.0]	438.0	[422.0, 454.0]	0.484

Table A. 11
Demographics (age and gender) of the group with imputed values. Per cent. N

	Male	Female
Age <35	20.9	22.2
Age 35–45	25.6	16.7
Age 45–65	41.9	55.5
Age >65	11.6	5.6
N	43	36

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