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Electrical support during outdoor cycling in patients with coronary artery disease: impact on exercise intensity, volume and perception of effort

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Abstract

Background

Electrical assisted bicycles (EAB's) could be used to overcome barriers and difficulties to outdoor cycling and thus assist in achieving a sufficient physical activity level in coronary artery disease (CAD) patients, but it is unknown whether sufficient exercise intensities and volumes could be elicited during cycling on EAB's. In this study we examined, for the first time, the acute physiological impact of electrical support during outdoor cycling in CAD patients (ISRCTN32238279).

Methods

Fifteen CAD patients (13 males), aged 64 ± 7 years executed a maximal cardiopulmonary exercise test and afterwards cycled a predefined outdoor route of 10 km, in three different conditions: classical cycling (no support), EAB with low support (EAB_{low}) and high support (EAB_{high}). Oxygen uptake (VO_2) and carbon dioxide output (VCO_2) was measured continuously by a portable gas-analyzing system. Cycling time was recorded and ratings of perceived exertion (RPE) was assessed at 3 and 7 km.

Results

Mean VO_2 during EAB_{high} ($1721 \pm 537 \text{ ml} \cdot \text{min}^{-1}$) was significantly lower compared to EAB_{low} ($1890 \pm 619 \text{ ml} \cdot \text{min}^{-1}$, $p < 0.05$), but no differences were found between EAB_{low} or classical cycling ($1846 \pm 523 \text{ ml} \cdot \text{min}^{-1}$). EAB_{low} and EAB_{high} elicited a sufficient volume and intensity ($6.6 \pm 2.0 \text{ MET's}$ ($74 \pm 6\% \text{ VO}_{2\text{peak}}$) and $6.0 \pm 1.8 \text{ MET's}$ ($68 \pm 7\% \text{ VO}_{2\text{peak}}$), respectively) to adhere to the guidelines for secondary prevention in CAD. RPE was significantly lower ($p < 0.05$) during EAB_{high} (9 ± 2), than during EAB_{low} (11 ± 2) or classical cycling (11 ± 2).

Conclusion

Outdoor cycling with electrical support leads to a sufficiently high exercise intensity and volume in CAD patients, and may be considered as an alternative exercise modality.

Key words

Coronary artery disease; electrical assisted bicycles; exercise intensity; exercise volume

Disclosure statement

No potential conflict of interest was reported by the authors.

Introduction

Cardiovascular disease is one of the main health problems, contributing to 47% and 40% of all deaths in Europe and the European Union, respectively [1]. After an acute coronary syndrome, cardiac rehabilitation is recommended by the European Society of Cardiology, the American Heart Association and the American College of Cardiology (Class IB), as part of secondary prevention [2]. In this regard, exercise training is acknowledged to be a core component in these programs, as it is known to decrease cardiovascular morbidity and mortality significantly [3-6]. It is recommended to preferably engage in moderate (3-6 MET) to vigorous (>6 MET) aerobic exercise training, ≥ 3 times a week and for >30 min per session. This translates in a minimum goal of >405 MET-min/week [2]. Despite the proven effectiveness of exercise training in cardiac rehabilitation (improvements in physical fitness and cardiovascular risk profile) [7-9], long-term adherence to exercise prescription is often disappointing. This translates into suboptimal control of physical fitness and cardiovascular risk profile in the long term [10,11]. Therefore, novel exercise training strategies/devices that have the potential to increase long-term participation rates are urgently needed.

Electrically assisted bicycles provide patients with an alternative to achieve physical activity recommendations, while at the same time reducing the difficulties with classical outdoor cycling (strong contrary wind, hilly courses) and/or with physical limitations (low physical fitness, orthopedic limitations). However, before such exercise modality can be recommended as part of secondary prevention programs for coronary artery disease (CAD), it should be studied whether cycling with electrical assistance elicits sufficient exercise intensities and volumes to contribute to meeting the international exercise training guidelines.

In healthy subjects, it has been found that cycling with both low and high electrical support reduces exercise intensity and/or volume, when compared to classical cycling [12-18], thus potentially leading to the risk of insufficient exercise intensities and volumes to improve

cardiovascular health. The acute physiological impact of electrical support during outdoor cycling in CAD patients has not been studied before and thus deserves greater attention.

The primary purpose of this study was to assess whether the exercise intensity and volume of cycling with low and high electrical support meets the exercise standards for secondary prevention in CAD. The secondary goal was to study the effect of low and/or high electrical support during outdoor cycling on ratings of perceived exertion.

Methods

Study design and patient recruitment

This study (ISRCTN registry: ISRCTN32238279) was a mono-center, prospective, randomized cross-over clinical trial, run at Jessa hospital (n=15) in Hasselt, Belgium between November 2014 and May 2015 (Figure 1). Patients aged between 50-75 years were eligible for participation when they had recently successfully completed phase II cardiac rehabilitation for CAD and treated medically, with a percutaneous coronary intervention or with coronary artery bypass graft surgery. The main exclusion criteria were (i) symptomatic and/or exercise induced cardiac arrhythmias within the previous six months, (ii) physical disability related to musculoskeletal or neurological problems, (iii) severe pulmonary co-morbidity (COPD GOLD III-IV), (iv) chronic kidney disease stage IV-V (GFR: $<30 \text{ ml} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-1}$) and (v) patients with a pacemaker, internal cardioverter defibrillator and/or cardiac resynchronization therapy device. All patients provided written informed consent, after the nature and possible consequences of the study were explained, prior to study enrollment. The study was conducted in accordance with the principles stated in the Declaration of Helsinki of the World Medical Association, local and national regulations. The study protocol was approved by the medical ethical committee of Jessa hospital and Hasselt university.

Study participants completed a maximal cardiopulmonary exercise test (CPET) at completion of their 12-week ambulatory rehabilitation program at Jessa hospital, and a classical bicycle cycling route was completed first after which they were randomly assigned to one of two study groups (group_{no-low-high} and group_{no-high-low}) (Figure 1). Randomization was performed using sealed and blinded envelopes. Patients in the group_{no-low-high} cycled the same route with low and high electrical assistance for the second and third time, respectively. Patients in the group_{no-high-low} cycled the same route with high and low electrical assistance for the second and third time, respectively. Between these routes, a 3-4-day recovery interval was respected.

Subject recruitment and characteristics

A total of 17 patients agreed to participate in the study (Figure 1). Two patients dropped out after the classical cycling session. There were technical problems with the bicycle for one patient, the other patient had difficulties to cycle without falling. The demographics, comorbidities, medication and initial maximal CPET results of study participants are shown in Table 1 and 2. Included patients (aged 64 ± 7 years) were predominantly male (87% (n=13)) and treated by percutaneous coronary intervention (PCI) (80% (n=12)) for their CAD.

Initial maximal cardiopulmonary exercise test (CPET)

Patients performed a maximal CPET [19,20] with a ramping protocol and breath-by-breath gas exchange analysis on an electrically braked cycle ergometer (Jaeger MS-CPX). The test was considered maximal in case of an achieved respiratory gas exchange ratio (RER) >1.1 , and/or a ventilatory reserve (VR: $VE_{peak} \cdot MVV^{-1}$) $>80\%$. Patients were instructed to cycle at 70 rpm, and the test was ended when the patient was no longer able to cycle >59 rpm. Oxygen uptake (VO_2), minute ventilation (VE) and carbon dioxide output (VCO_2) were measured continuously and averaged every 10 seconds. The first ventilatory threshold (VT1) was

defined by V-slope method. Patients with cardiac arrhythmias and/or (silent) myocardial ischemia were excluded from this study.

Experimental procedure

Two types of bicycles were used: the Montego (classical bicycle) without electrical support, and the E-bike (e.move, Temse, Belgium, model: c300) electrically assisted bicycle with low (EAB_{low}) and high support (EAB_{high}) mode. The electrically assisted bicycle was equipped with a motor located in the hub of the front wheel, providing an additional mechanical support up to 250 W and a maximal assisted speed of 25 km•h⁻¹. It could provide electrical assistance with 6 incremental support modes. Electrical assistance was provided up to 12-13 km•h⁻¹ in mode 1, 16-17 km•h⁻¹ in mode 2, 19-20 km•h⁻¹ in mode 3, 22-23 km•h⁻¹ in mode 4, 23-24 km•h⁻¹ in mode 5 and 25 km•h⁻¹ in mode 6. Each time, the saddle and handlebars were repositioned to suit each subject. Participants were familiarized with the electrically assisted bicycle prior to starting the cycling route, in order to be able to use it appropriately. EAB_{low} was defined as support mode 1 and EAB_{high} as mode 2 in case patients cycled on average <16 km•h⁻¹ during the classical cycling sessions. EAB_{low} was defined as support mode 2 and EAB_{high} as mode 4 in case patients cycled on average >16 km•h⁻¹ during the classical cycling sessions.

Patients cycled on a public track in x. The track had an up-and-down course (102-m height difference) and a length of 10 km. Tests were conducted from 13.00 p.m. to 17.00 p.m.. The weather conditions ranged from 0°C to 17°C, a wind speed between 3 km•h⁻¹ and 41 km•h⁻¹, and a rainfall between 0 mm•day⁻¹ and 8 mm•day⁻¹. Tests were performed in real traffic, no stop-and-go points were built in the protocol. Patients were instructed to cycle at a self-selected comfortable speed, they did not receive any feedback during or after the cycling

sessions. One researcher cycled behind the patient for safety reasons and to assist if necessary (in case of mechanical problems).

Outcome measures

The parameters measured during the cycling sessions were VO_2 , VCO_2 , VE , RER , cycling time and ratings of perceived exertion (RPE). VO_2 ($\text{ml}\cdot\text{min}^{-1}$), VE ($\text{ml}\cdot\text{min}^{-1}$) and VCO_2 ($\text{ml}\cdot\text{min}^{-1}$) were determined (averaged every 10 seconds) by analysis of expired gases by using a mobile Jaeger ergospirometer (OxyconTM mobile device). VO_2 measurements were referred to the patients' $\text{VO}_{2\text{peak}}$ ($\%\text{VO}_{2\text{peak}}$) as deduced from the initial maximal CPET. Exercise intensity was estimated by converting VO_2 into MET ($1 \text{ MET} = 3.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1} \text{ VO}_2$). The mean MET value per cycling session was computed and averaged for classical cycling, EAB_{low} and EAB_{high} . For each of these three conditions, the % of patients cycling at a low, moderate and vigorous intensity (defined as <3 MET's, 3-6 METs and >6 METs respectively) was calculated. Cycling time was measured by chronometry (Xonix watch). Total exercise volume was expressed in MET-min by multiplying the mean MET score and the total cycling time (min). Energy expenditure (kcal) was calculated by the following formula: number of kcal = MET x weight (kg) x cycling session duration (hours). The Borg scale (6-20) was used to assess subjectively reported RPE at two predefined locations (at 3 and 7 km of cycling route). Only effective cycling periods were included in the final analysis.

Statistical analysis

Data analysis was performed using SPSS v. 22. The Shapiro-Wilk test was used to assess normality. Nonparametric tests were used instead of parametric statistics in case assumptions for normality were violated. Repeated measures ANOVA (parametric) or Friedman's ANOVA (non-parametric) compared multiple dependent means. If significant effects were

observed, post-hoc contrasts with Bonferroni corrections were performed to determine which conditions differed. The significance level for tests was 2-sided α of 0.05. Continuous variables were reported as mean \pm SD, categorical variables as % (N). Since this was the first study to examine the acute physiological impact of electrical support during cycling in CAD patients, it was difficult to execute an a priori sample size calculation. However, it was decided to execute an interim sample size calculation when nine subjects were examined (who were studied before January 2015), based on caloric expenditure. During this calculation, it was found that >14 subjects had to be included in the present study to be able to detect significant differences in caloric expenditure between different cycling conditions ($p < 0.05$, two-tailed, power $\alpha > 0.80$). For these calculations, GPower v 3.1 was used.

Results

Exercise intensity

There was a significant main effect of level of electrical support on mean VO_2 ($p=0.018$, Table 3) during cycling. Post-hoc contrasts revealed that the mean VO_2 ($1846 \pm 523 \text{ ml} \cdot \text{min}^{-1}$) during classical cycling sessions were not different from mean VO_2 ($1890 \pm 619 \text{ ml} \cdot \text{min}^{-1}$) during EAB_{low} , $p=1.00$. Mean VO_2 during EAB_{low} was however higher, compared to EAB_{high} ($1721 \pm 537 \text{ ml} \cdot \text{min}^{-1}$, $p=0.038$), indicating a difference in exercise intensity.

There was a significant main effect of level of electrical support on mean MET's during cycling ($p=0.016$, Table 3). Post-hoc contrasts showed significant greater MET's during EAB_{low} (6.6 ± 2.0 MET's), as opposed to EAB_{high} (6.0 ± 1.8 MET's, $p=0.027$).

During classical cycling, 0% ($n=0$) of patients performed in the low, 40% ($n=6$) in the moderate and 60% ($n=9$) in the vigorous exercise intensity zones. During EAB_{low} , the respective percentages were 0% ($n=0$), 47% ($n=7$) and 53% ($n=8$). During EAB_{high} , the respective percentages were 0% ($n=0$), 67% ($n=10$) and 33% ($n=5$).

Cycling time

Total cycling time differed significantly between the three conditions ($p<0.001$, Table 3). Post-hoc contrasts revealed the total cycling time to be smaller ($p<0.05$) during EAB_{high} (31 ± 4.7 min) compared to EAB_{low} (35 ± 5.3 min) and classical cycling (37 ± 6.5 min).

Energy expenditure

Total caloric expenditure differed significantly between conditions ($p<0.001$, Table 3). During EAB_{high} energy expenditure was lower (249 ± 53 kcal, $p<0.05$), when compared to EAB_{low} (301 ± 57 kcal) or classical cycling (312 ± 45 kcal).

Ratings of perceived exertion

RPE was significantly different between conditions ($p=0.001$, Table 3), and lower ($p<0.05$) during EAB_{high} (9 ± 2), when compared to EAB_{low} (11 ± 2) and classical cycling (11 ± 2).

Discussion

In this study, it was investigated for the first time whether outdoor electrically assisted cycling was able to elicit exercise intensities and volumes that adhere to the international exercise training guidelines for secondary prevention in CAD. It was shown that sufficient exercise intensities and volumes were elicited during cycling, even with high electrical support, and could thus be considered as an alternative exercise modality to stimulate outdoor physical activity in CAD patients.

The elicited exercise intensity during EAB_{high} was lower (68% of VO_{2peak}, 6.0±1.8 MET's) as opposed to EAB_{low} (74% of VO_{2peak}, 6.6±2.0 MET's) but was still sufficiently high to adhere to international exercise standards (3-6 MET) for secondary prevention in CAD patients. 60% (n=9) of CAD patients during classical cycling achieved a mean intensity of >6.0 MET's. During EAB_{low} and EAB_{high}, 53% (n=8) and 33% (n=5), respectively, met the standards for vigorous-intense exercise (>6.0 MET's). The belief that electrical assistance during cycling should be avoided in exercise training of CAD patients should thus be reconsidered. Furthermore, the findings in this study showed that high electrical support during cycling led to a significant reduction in RPE (9±2, p=0.007) and could thus lower barriers for the least-fit patients, by assisting for hilly environments or strong contrary winds, but also for (earlier onset of) fatigue. It is thus speculated, although it remains to be shown in subsequent studies, that the use of EAB's may lead to enhanced adherence to physical activity recommendations and greater cardiovascular disease risk control on the long term in CAD patients.

These findings are well in line with previous studies in which healthy participants were studied. Gojanovic *et al.* compared the physiological response during classical cycling, and during EAB_{low} and EAB_{high} in 18 sedentary subjects [12]: during EAB_{low} and EAB_{high} cycling exercise was less intense, when compared to classical cycling. Louis *et al.* compared the aforementioned three cycling modes within 10 trained and 10 untrained subjects and also

observed an exercise intensity reduction during electrical support [13]. Similar differences were found in other studies [16,17]. Contrary to these findings, we only found a significant exercise intensity reduction during EAB_{high}. Exercise intensity was similar between classical cycling and EAB_{low} in our study. Given the fact that an electrically assisted bicycle on average weighs 13kg more than a conventional bicycle, the electrical support in EAB_{low} could have been insufficient to compensate for this increased mass, hence resulting in similar exercise intensities. Our results remain thus to be verified in a design in which an electrically assisted bike would be used during the classical cycling condition. On the other hand, CAD patients may ask their treating cardiologist whether they should ride a conventional bike or on an electrical assisted bike with electrical support in order to maintain their cardiorespiratory fitness, which is examined in the present study.

Cycling time and hence energy expenditure (as a derivative of both exercise intensity and cycling time) were significantly different between the three cycling conditions ($p < 0.001$). Post-hoc contrasts yielded only differences between EAB_{high} and other cycling conditions. Total energy expenditure was similar during classical cycling and EAB_{low}. It thus follows that patients using the EAB_{high} need to prolong their cycling time by 20%, to achieve a comparable total caloric expenditure, as opposed to classical cycling or EAB_{low}. However, even though compensations in total energy expenditure can be achieved by cycling longer when receiving (greater) electrical support, a lower exercise intensity remains present. It therefore remains to be studied whether similar clinical benefits of cycling can be achieved when electrical support is offered during a physical activity programme (of several weeks to months) in patients with CAD.

The present study faces some methodological strengths and limitations. To the authors' knowledge, this study was the first to investigate the acute physiological impact of electrical support during cycling in CAD patients. Study participants also cycled outdoor, thus

simulating real-life conditions. The continuous registration of VO₂ by analysis of expired gases during the cycling sessions provided a direct measure of exercise intensity and volume. However, the weather conditions were different between the cycling conditions, possibly biasing the results, but obviously could not be controlled by the investigators. For example, worse or better weather conditions (especially rain and wind) could elevate or lower the metabolic demand and/or perception of effort to complete the cycling route.

In conclusion, outdoor cycling with electrical support leads to sufficiently high exercise intensities and volumes in CAD patients, and may be considered as an alternative exercise modality. When selecting high electrical support during cycling, it is advised to prolong the cycling session to achieve similar caloric expenditures, as opposed to classical cycling or cycling with low electrical support.

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Figure Captions

Figure 1. Study flowchart. EAB low: electrically assisted cycling with low support, EAB high: electrically assisted cycling with high support.

Figure 2. Percentage of route cycled at 3-6 METs or >6 METs for each subject separately

A. Percentage of route cycled between 3-6METs for each subject

B. Percentage of route cycled >6METs for each subject

EAB low: electrically assisted cycling with low support, EAB high: electrically assisted cycling with high support.

Table 1. Demographics, co-morbidities and medication of study participants.

Demographics		Co-morbidities		Medication	
Age	64 ± 7	Blood pressure		On Beta blocker	67 % (10)
Gender		Normal (SBP < 140 mmHg and DBP < 90 mmHg)	67 % (10)	On Statin	93 % (14)
	Male	AHT Grade I (SBP 140-159 mmHg and/or DBP 90-99 mmHg)	20 % (3)	On ACE-inhibitor/ARB	73 % (11)
	Female	AHT Grade II (SBP 160-179 mmHg and/or DBP 100-109 mmHg)	0 % (0)	On Anti-platelet therapy	
		AHT Grade III (SBP ≥180 mmHg and/or DBP ≥110 mmHg)	13 % (2)	DAPT	60 % (9)
		Diabetes mellitus (HbA1c >6.5% and fasting glucose > 126 mg/dl or random glucose > 200 mg/dl)	13 % (2)	Anti-platelet monotherapy	40 % (6)
CAD clinical presentation		Smoking		On oral anti-diabetics	7 % (1)
	STEMI	No	47 % (7)	On Insulin	7 % (1)
	NSTEMI	Current smoker	20 % (3)	On Diuretics	7 % (1)
	UA	Prior smoker	33 % (5)	On Anti-arrhythmics	7 % (1)
	SA				
No of vessels involved		Hyperlipidemia	73 % (11)		
	1	Weight			
	>1	Normal (BMI 18.5-24.9 kg/m ²)	27 % (4)		
Vessels involved		Overweight (BMI 25-29.9 kg/m ²)	47 % (7)		
	RAC	Obesity Grade I (BMI 30-34.9 kg/m ²)	27 % (4)		
	LAD	Obesity Grade II (BMI 35-39.9 kg/m ²)	0 % (0)		
	Cx	Obesity Grade III (BMI ≥40 kg/m ²)	0 % (0)		
Therapy for CAD		Familial history	60 % (9)		
	PCI	Peripheral arterial disease	20 % (3)		
	CABG				

AHT: arterial hypertension, ARB: angiotensin receptor blocker, CAD: coronary artery disease, DAPT: dual anti-platelet therapy, STEMI: ST-elevation myocardial infarction, NSTEMI: non-ST elevation myocardial infarction, UA: unstable angina, SA: stable angina, No: number, RCA: right coronary artery, LAD: left anterior descendens artery, Cx: circumflex artery, PCI: percutaneous coronary intervention, CABG: coronary artery bypass grafting.

Normal blood pressure (SBP < 140 mmHg and DBP < 90 mmHg), AHT Grade I (SBP 140-159 mmHg and/or DBP 90-99 mmHg), AHT Grade II (SBP 160-179 mmHg and/or DBP 100-109 mmHg), AHT Grade III (SBP ≥180 mmHg and/or DBP ≥110 mmHg). Diabetes mellitus is defined as HbA1c > 6.5% and fasting glucose > 126 mg/dl or random glucose > 200 mg/dl. Normal weight (BMI 18.5-24.9 kg/m²), overweight (BMI 25-29.9 kg/m²), obesity Grade I (BMI 30-34.9 kg/m²), obesity Grade II (BMI 35-39.9 kg/m²), obesity Grade III (BMI ≥40 kg/m²).

Table 2. Baseline maximal cardiopulmonary exercise test results of study participants.

	Mean	SD	Range
RERmax	1.2	0.1	1.1-1.3
HRrest (bpm)	80	13	56-113
HRmax (bpm)	132	20	94-155
DBPrest (mmHg)	79	17	55-121
DBPmax (mmHg)	92	20	58-146
SBPrest (mmHg)	124	26	97-186
SBPmax (mmHg)	169	23	136-217
VO2 peak (ml/min)	1,971	620	1,211-3,388
VO2 peak (ml/min/kg)	24	7	16-39
HRmax (% pred)	84	12	61-103
Watt (W)	173	68	93-330
VT1 (ml/min)	1,432	414	734-2,123
VE peak (l/min)	85	27	51-150
VCO2 peak (ml/min)	2,382	798	1,436-4,324

RER: respiratory exchange ratio, HR: heart rate, DBP: diastolic blood pressure, SBP: systolic blood pressure, VO2 peak: peak oxygen consumption, VT: ventilator threshold, VE: minute ventilation, VCO2: carbon dioxide output.

Table 3. Physiological variables during the cycling tests with the classical bike, the electrically assisted bicycle with low support and high support respectively.

	Classical bicycle		EAB low		EAB high		<i>P overall</i>	<i>P No vs L</i>	<i>P No vs H</i>	<i>P L vs H</i>
	Mean	SD	Mean	SD	Mean	SD				
VO2 mean (ml/min)	1,846	523	1,89	619	1,721	537	.018	1.0	.204	.038
%VO2 peak	73	4.6	74	6.2	68	7.1	.012	1.0	.091	.029
METs	6.4	1.6	6.6	2.0	6.0	1.8	.016	1.0	.201	.027
Cycling time (min)	37	6.5	35	5.3	31	4.7	< .001	.301	< .001	< .001
MET-minutes	230	24	222	36	183	36	< .001	1.0	< .001	< .001
Kcal	312	45	301	57	249	53	< .001	1.0	< .001	< .001
RPE (Borg scale 6-20)	11	2	11	2	9	2	.001	.486	.007	.014
VE (l/min)	60.7	16.0	63.9	20.9	55.0	16.8	.006	.463	.168	.018
VCO2 (ml/min)	1,742	531	1,734	569	1,542	496	.003	1.0	.028	.031
RER	0.9	0.1	0.9	0.1	0.9	0.1	.095	NA	NA	NA

EAB: electrically assisted bicycle, SD: standard deviation, VO2: oxygen consumption, MET: metabolic equivalents, RPE: rate of perceived exertion, VE: minute ventilation, VCO2: carbon dioxide output, RER: respiratory exchange ratio.

Figure 1

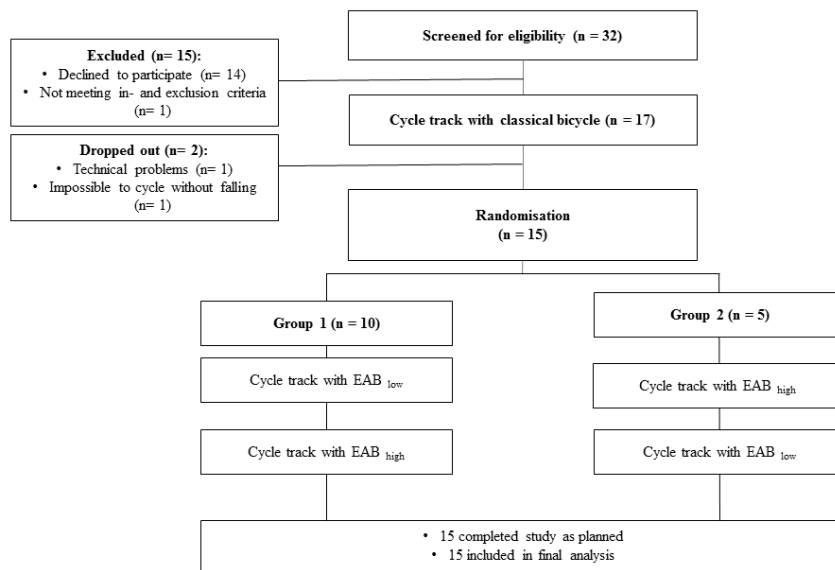
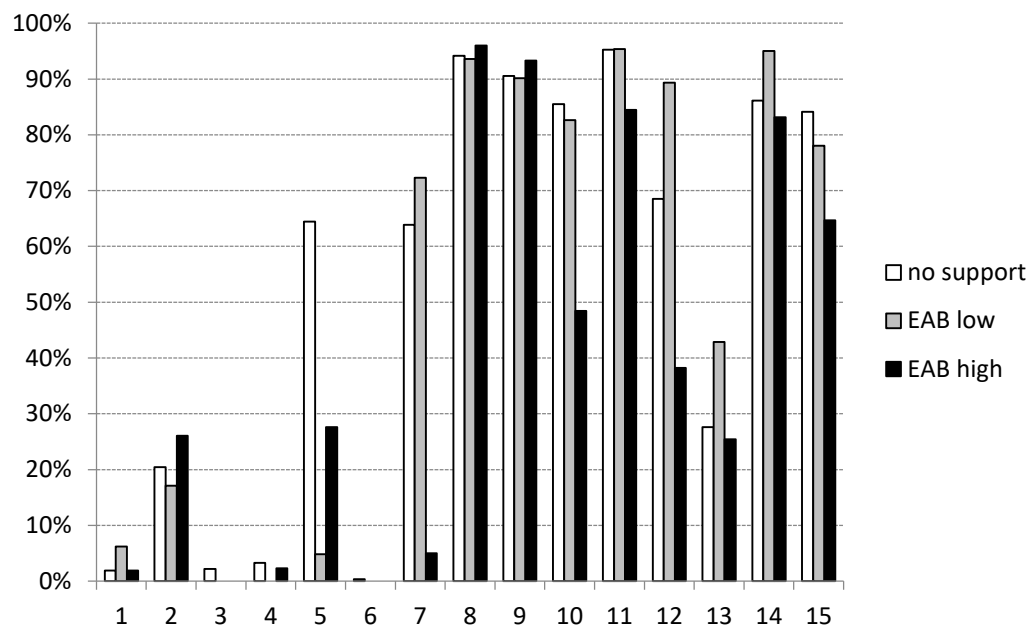


Figure 2

A.



B.

