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THE RELATIONSHIP BETWEEN BICYCLE COMMUTING AND PERCEIVED STRESS: A CROSS-SECTIONAL STUDY

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ABSTRACT

Introduction: Active commuting –walking and bicycling for travel to and from work or educational addresses– may facilitate daily routine physical activity. Several studies have investigated the relationship between active commuting and commuting stress, but there is no literature studying the relationship between bicycle commuting and perceived stress, nor taking into account environmental determinants. The current study evaluated the relationship between bicycle use for commuting among working or studying adults in Barcelona (Spain) and perceived stress.

Methods: A cross-sectional study was performed with 788 adults who regularly travelled to work or study locations in Barcelona. Participants responded to a comprehensive telephone survey concerning their travel behaviour from June 2011 through to May 2012. Participants were categorised as either bicycle commuters or non-bicycle commuters, and based on the Perceived Stress Scale (PSS-4) as stressed or non-stressed. Multivariate logistic regression models of stress status based on bicycling exposure, adjusting for potential confounders, were estimated. The data was analyzed between May and October 2015.

Results: Bicycle commuters had significantly lower odds of being stressed [OR (95%CI) = 0.61 (0.46, 0.83)]. Bicycle commuters who bicycled four or more days per week had lower perceived stress than those who bicycled less than that. This relationship remained significant when adjusting by individual and environmental determinants, and when using a different cut-off of perceived stress (P50, P75, P90).

Conclusions: Stress reduction may be an important consequence of routine bicycle use and may need to be considered by decision makers as another potential benefit of bicycle use.

STRENGHTS AND LIMITATIONS OF THIS STUDY

- The study had high internal validity, with a good representation of bicycle commuters.
- The study was conducted in Barcelona (a southern European city), adding evidence in a different context than the current literature on these issues.
- The TAPAS Travel Survey sample is representative of Barcelona's population, taking into account deprivation index and home and work population density.
- The study used a cross-sectional design, which is not well-suited to assess the direction of causation.
- Using questionnaire data we could have misclassification error (information bias) of bicycle commuting and PA because of the data being self-reported.

INTRODUCTION

Increasing physical activity (PA) is one of the key approaches to reduce non-communicable diseases. In 2010, physical inactivity and low PA accounted globally for approximately three million premature deaths, and 2.8% (2.4–3.2) of DALYs.(1) Active commuting – walking and bicycling for travel to and from work or educational addresses – seems to be well suited to increase physical activity levels in general population,(2,3) as it needs less time and motivation. Emerging literature is exploring the health benefits of active commuting. It has been suggested that greater time spent actively commuting is associated with higher levels of physical and mental well-being(4,5) and better mental health in men.(6) Specifically bicycle commuting has been shown as inversely associated with all-cause mortality among both men and women in all age groups(7) and it seems to be likely to improve the health-related quality of life in previously untrained healthy adults.(8)

Perceived stress presents a global and comprehensive stress construct that refers to the interaction between the individual and the environment when a stressor occurs.(9) The perception of an event as stressful can result in a range of physiological, behavioural, and psychological changes, such as cardiovascular disease, increased negative affect, lowered self-esteem, and lowered feelings of control. Hence, anxiety disorders and depression can be manifestations of chronic (perceived) stress.(10) It has been suggested that moderate-intensity physical activity may reduce stress and anxiety on a daily basis while improving self-perception and mood.(11,12) Some literature recognise commuting as a potential source of stress,(13) but recent qualitative research suggests that commuting is often perceived as a relaxing or transitional time between home and work life, which can also be about enjoying pleasant landscape, nature and wildlife.(14) Active commuters have shown higher levels of satisfaction, less stress, relaxation and a sense of freedom than car drivers.(15–17) The use of

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a bicycle for commuting has been also considered a fast transport mode and associated with a sense of freedom too.(18) Reinforcing the argument of pleasantness and practicality for bicycle commuting, objective measurements found that the quantity of public bicycle (*Bicing*) stations within the home area, and amount of greenness within the work/study area were positive determinants of propensity for bicycle commuting.(19)

Several studies have investigated the relationship between active commuting and commuting stress (stress directly related with the fact of commuting),(16,17,20,21) a few studies have investigated the relationship between active commuting and well-being,(4–6) but none of them have studied the relationship between adult bicycle commuters and perceived stress, nor taking into account environmental determinants. Moreover, most studies of active commuting benefits on mental health have been conducted in North America or Northwest Europe.(4–6,16,21,22) Consequently, there is a need to better understand the relationship between bicycle commuting and perceived stress, and specifically in a sample of residents in a Southern European city.

The current study aimed to evaluate the relationship between bicycle commuting among the working or studying adult population of Barcelona (Spain) and perceived stress.

MATERIALS AND METHODS

Study population

This cross-sectional study was based on participants from the Transportation, Air Pollution and Physical ActivitieS (TAPAS) Travel Survey. TAPAS was a large study that investigated the risks and benefits of active commuting. Adult bicycle commuters and non-bicycle

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commuters who fulfilled the inclusion criteria (being older than 18 years of age; living in Barcelona city since 2006 or earlier; working or going to school in Barcelona city; being healthy enough to ride a bicycle for 20 minutes; having at least 10 minutes of walking commute; and using at least one mode of transport other than walking to commute) were recruited between June 2011 and May 2012. Participants were recruited from four randomlyselected locations within each of the ten city districts across Barcelona (for a total of 40 locations) to ensure adequate geographic coverage. In the recruitment process, pedestrians were excluded from the non-bicycle commuters as the main interest was in the contrast of motorized modes (private and public transportation) and the bicycle. Further details of the recruitment are given in Donaire-Gonzalez et al 2015.(3)

The study protocol was approved by the Clinical Research Ethical Committee of the Parc de Salut Mar (CEIC-Parc de Salut Mar), and written informed consent was obtained from all participants.

Bicycle commuters

The TAPAS Travel Survey assessed the common use of transport modes(23) and the bicycle use.(24) Participants who indicated use bicycle (private or from public bike sharing system) as transport at least once the week prior to survey administration were classified as "bicycle commuters". Participants who indicated use bicycle (private or from public bike sharing system) as transport and did not commute by bicycle in the week prior to survey administration were classified as "non-bicycle commuters".

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As part of the sensitivity analyses, the commuting behaviour was also classified by three different bicycle commuting levels taking into account the frequencies of bicycle commuting use and by bicycle commuting propensity.(19)

Regarding bicycle commuting levels, "Bicycle commuters" were further classified as "low bicycle commuters", "medium bicycle commuters" and "high bicycle commuters". "Bicycle commuters" who commuted by bicycle on five or more days in the week prior to survey administration were classified as "high bicycle commuting". Those who had commuted by bicycle on four days in the week prior to survey administration were classified as "medium bicycle commuting". Finally, those who commuted by bicycle on three days or fewer in the week prior to survey administration were classified as "low bicycle commuting".

Regarding bicycle commuting propensity, details of the classification are given in Cole-Hunter et al 2015.(19)

Perceived stress

The last four questions of the TAPAS Travel Survey were the short version of Perceived Stress Scale (PSS-4),(9) which is an economical and simple psychological instrument to administer, comprehend, and score. PSS-4 measures the degree to which situations in one's life over the past month are appraised as stressful. The instrument contains four statements, which measure how unpredictable, uncontrollable, and overloaded respondents feel that their lives are (Table S1). The higher the score on the PSS-4 (from 0 to 16), the greater the respondent perceives that their demands exceed their ability to cope. There are no cut-off scores. Instead, an individual's score is compared to a normative value.(25) In the TAPAS Travel Survey the 5-point Likert scale was modified to a 4-point Likert scale, removing the

midpoint option for consistency across the survey, because all of other questions from the survey were on a 4-point Likert scale. Participants assigned a PSS-4 score higher than 3 (median of the total sample) were classified as "stressed", and those equal or lower than 3 were classified as "non-stressed".

As part of the sensitivity analyses, the PSS-4 score was also classified separately by percentile 75 (P75) and percentile 90 (P90): participants assigned a PSS-4 score higher than 4 (P75) and 6 (P90) were classified as "stressed", and those who got a PSS-4 score equal or lower than 4 and 6 were classified as "non-stressed" in respective, separate analyses.

Other explanatory measures

Individual determinants such as physical activity levels,(26) socio-demographic variables, and work or school addresses were also derived from the TAPAS Travel Survey. In addition, the MEDEA Index was used as an area deprivation indicator assigned to each respondent's address. MEDEA measures deprivation at the census tract level based on five domains including percentage of manual workers, temporary workers, total population with low education, young population with low education, and unemployment.(27)

Environmental determinants within a 400m buffer surrounding home and work/study addresses, and a Route-By-Area (RBA) surrounding predicted commute routes, were calculated.(19) Greenness was calculated as a mean and percentiles in Normalized Difference Vegetation Index (NDVI) via satellite imagery (LANDSAT 4 and 5, NASA). NO2 levels were estimated as a mean and percentiles using a land-use regression model developed for a previous project.(28) Noise was calculated as a mean and percentiles in dB(A) level equivalent (LAeq) modeled using measured noise and transit data from Barcelona's strategic

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noise map developed in the year 2007(29) based upon previous work.(30) The noise variable used for analyses was the proportion of street length above a 55 dB(A) threshold.(31) Also measured were bicycle parking and lanes digitized from existing maps.(32) A bikeability index was calculated taking into account five factors shown to influence bicycling: bicycle facility availability, bicycle facility quality, street connectivity, topography, and land use.(33) Further details of the environmental determinants calculation are given in Cole-Hunter et al 2015.(19)

Statistical analyses

A GAM was used to test linearity between bicycle commuters and perceived stress. Multivariate logistic regression models were used to assess the relationship between bicycle commuters and perceived stress. Possible mediation by different levels of PA between bicycle commuters and perceived stress, and any interaction between sex and bicycle commuters were also tested with logistic regression models. All regression models were conducted with a complete case analysis and included potential confounders that showed a p-value <0.05 in the bivariate analysis as well as those found to be statistically-significant within previous literature. All statistical analyses were conducted in Stata version SE 12 (StataCorp LP, Texas USA) between May and October 2015.

RESULTS

The TAPAS database consisted of 789 subjects. After excluding one PA outlier (total of all walking, moderate and vigorous time variables >960 minutes/day) 788 remained. The included sample had an equal distribution of sexes and the median age (interquartile range, IQR) was 36 (14) years (Table 1). The majority of subjects were non-stressed (had a stress score equal or lower than 3), Spanish, possessing university studies completed or equivalent-

 level education, living with their family or partner, living with at least 2 employed people and not with children (64.34%). Among those living with children, 8.12% had children younger than 3 years of age. The sample had positive self-perception of health (with only <1% of subjects self-perceiving bad or very bad health), healthy weight according to BMI (71.12%), and generally no chronic disease (92.26%). Bicycle commuters were statistically-significant more likely to be non-stressed, younger (35 years), male, and non-Spanish; to possess university studies completed or equivalent-level education; to live alone and/or with flat mates, with 0-1 employed people, and no children; and to have higher levels of PA, better self-perception of health, and healthy weight, but more chronic diseases than non-bicycle commuters. The majority of subjects considered that they could release stress when riding a bicycle and that they enjoyed their trip more if they used a bicycle. Related to environmental determinants, bicycle commuters had shorter commutes, more public bicycle stations around the home and work/study address, lower average greenness around the home address, and higher levels of bikeability at home and work/study address compared with non-bicycle commuters.

Females and non-Spanish and those living with less than 2 employed people were more likely to be stressed (Table 2). Related to environmental determinants, participants who had more public bicycle stations around their work/study area and higher levels of bikeability in the work/study address area and on the commute route were less likely to be stressed. There was no statistically-significant relationship between commute distance, greenness, NO₂ and noise, and perceived stress. The possible mediation of PA was not further explored as there was no statistically-significant relationship between levels of PA (Total PA, MVPA and VPA) and perceived stress [OR: 1.00; 95% CI: (0.99, 1.00)] for the three different classifications of perceived stress (P50, P75, P90) (Table 2, Table S3).

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Table 1. Perceived stress and determinants of participants and according to bicycle

commuting status.

	Trailer	(799)		Bicycl	e commuting sta	atus	
Variables	l otal sa	mple (788)	Non-bicycle co	ommuters (390)	Bicycle com	muters (398)	n valua ^a
	n	%	n	%	n	%	p-value
0.4							
Outcome	280	25 52	162	41.07	118	20.22	0.001
Stressed (median) (Yes)	280	55.55	102	41.97	118	50.55	0.001
Individual determinants							
Age (median; IQR)	36	14	37	15	35	12	0.025
Total PA – min/week (median;IQR)	424.99	430.00	374.99	415.00	484.98	405.00	< 0.001
MVPA – min/week (median;IQR)	197.49	302.49	90.00	240.00	299.99	305.00	< 0.001
VPA – min/week (median;IQR)	72.50	180.00	35.00	134.99	105.00	225.00	< 0.001
Sex (Female)	410	52.03	234	60.00	176	44.22	< 0.001
Country of birth (non-Spanish)	97	12.31	41	10.51	56	14.11	0.125
Working status (Student)	104	13.20	347	87.19	51	12.81	0.748
Education level (University studies completed or equivalent-level education)	551	69.92	247	63.33	304	76.38	< 0.001
Living with family/partner	635	80.58	327	83.85	308	77.58	0.026
Employed people in household (>2)	510	64.72	261	67.27	249	62.88	0.198
MEDEA index							0.355
1st tertile (least deprived)	263	33.38	130	33.33	133	33.42	
2nd tertile	263	33.38	122	31.28	141	35.43	
3rd tertile (most deprived)	262	33.25	138	35.38	124	31.16	
Children in household (Yes)	279	35.41	151	38.82	128	32.24	0.054
Children <3 years in household (Yes)	64	8.12	36	9.25	28	7.07	0.264
Self-perceived health (Very good/Excellent)	323	40.99	140	35.90	183	45.98	0.004
BMI (Overweight/Obese)	212	26.9	124	31.96	88	22.11	0.002
Chronic disease (Yes)	61	7.74	25	6.41	36	9.05	0.166
Stress releasing (Agreement)	658	83.50	302	/9.4/	350	90.59	< 0.001
Bicycle trip enjoyment (Agreement)	029	19.02	249	05.55	380	90.20	<0.001
Environmental determinants							
Commute distance, estimated (km) (median;IRQ)	3.52	2.56	3.93	2.77	3.08	2.29	< 0.001
Public bicycle stations (median;IQR)							
Home, count in 400m buffer	4	3	4	3	4	3	< 0.001
Work/study, count in 400m buffer	5	4	4	4	5	4	< 0.001
Greenness, NDVI [IOR, (median; IOR)]							
Home average of 400m buffer	0.52	1.00	0.65	1.06	0.47	0.84	< 0.001
Work/study average of 400m buffer	0.35	1.00	0.38	1.06	0.33	0.89	0.086
Commute route average of RBA	0.69	1.00	0.72	1.20	0.67	0.87	0.062
NO ₂ , ppb (median;IQR)							
Home, concentration in 400m buffer	76.70	25.82	74.60	25.33	78.44	25.76	0.058
Work/study, concentration in 400m buffer	81.36	33.73	80.98	35.97	81.91	31.01	0.843
Commute route, concentration in RBA	85.21	22.65	85.54	22.56	84.89	22.64	0.987
Noise, >55dB (%) (median;IQR)							
Home, proportion in 400m buffer	79.41	14.24	79.05	12.96	79.53	15.14	0.823
Work/study, proportion in 400m buffer	80.89	22.99	80.51	23.54	81.40	22.67	0.369
Commute route proportion in RBA	77.15	11.66	77.06	10.86	77.34	12.51	0.924
Bikeability (median:IOR)							
Home concentration in 400m huffer	6 34	2 25	77.06	10.86	77 34	12.51	0 924
Home, concentration in 400m buffer	6.07	2.23	5.04	2 25	6.60	1.87	<0.001
Work/study, concentration in 400m buffer	0.92	2.01	3.94	2.23	0.09	1.0/	~0.001
Commute route, concentration in RBA	6.89	1.55	6.64	1.75	/.10	1.24	< 0.001

PA, Physical Activity, MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; BMI, Body Mass Index. Data are n and %, unless otherwise noted. There are missing data in: Perceived stress (13; 1.65%), Country of birth (1; 0.13%), Living with family/partner (1; 0.13%), Employed people in household (4; 0.51), Children in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂ (20; 2.54%). *Chi square test, instead of Age, Total PA, MVPA, VPA, and all the Environmental determinants (U Mann Whitney test).

Table 2. Relationship between perceived stress (median) and determinants of participants.

Variable		Perceived str	ess
variable	OR	(95% CI)	p-value
Individual determinants			
	1.00	(0.98, 1.01)	0.493
Total PA - min/week	1.00	(0.90, 1.01)	0.665
MVDA min/week	1.00	(0.99, 1.00)	0.005
VPA min/week	1.00	(0.99, 1.00)	0.102
Say (Famala)	1.00	(0.99, 1.00) (1.46, 2.67)	<0.004
Country of brith (Voc)	1.50	(1.40, 2.07) (1.06, 2.51)	<0.001
Working status (Student)	1.05	(1.00, 2.51) (0.01, 2.11)	0.027
Education level (University studies completed	1.56	(0.91, 2.11)	0.151
or Others)	0.87	(0.64, 1.20)	0.391
Living with family/partner	0.87	(0.04, 1.20)	0.446
Employed people in household (\$2)	0.67	(0.00, 1.23) (0.46, 0.84)	0.002
MEDEA index	0.02	(0.40, 0.84)	0.002
1st tertile (least deprived)	1.00		
2nd tertile	1.00	(0.78, 1.61)	0 537
2nd tentile (mont demnined)	1.12	(0.76, 1.01)	0.337
Children in household (Ves)	1.29	(0.90, 1.80) (0.62, 1.17)	0.101
Children (2 mars in household (Van)	0.80	(0.03, 1.17) (0.47, 1.41)	0.323
Children <3 years in nousehold (Yes)	0.81	(0.47, 1.41)	0.461
Self-perceived health (very good/Excellent)	0.80	(0.59, 1.09)	0.154
Changing (Verweight/Obese)	0.93	(0.67, 1.30)	0.666
Chronic disease (Yes)	1./4	(1.02, 2.95)	0.041
Stress releasing (Agreement)	0.80	(0.53, 1.20)	0.287
Bicycle trip enjoyment (Agreement)	0.86	(0.59, 1.25)	0.432
Environmental determinants			
Commute distance, estimated (km)	1.02	(0.95, 1.10)	0.511
Public bicycle stations			
Home, count in 400m buffer	0.98	(0.92, 1.04)	0.500
Work/study, count in 400m buffer	0.94	(0.90, 0.99)	0.021
Greenness, NDVI [IQR, (median; IQR)]			
Home, average of 400m buff	0.91	(0.79, 1.05)	0.215
Work/study, average of 400m buffer	1.09	(0.94, 1.27)	0.260
Commute route, average of RBA	0.98	(0.84, 1.15)	0.837
NO ₂ ppb (median;IQR)			
Home, concentration in 400m buffer	1.00	(0.99, 1.01)	0.824
Work/study, concentration in 400m buffer	0.99	(0.99, 1.00)	0.110
Commute route, concentration in RBA	1.00	(0.99, 1.01)	0.516
Noise, >55dB (%) (median;IQR)			
Home, proportion in 400m buffer	0.99	(0.98, 1.01)	0,363
Work/study, proportion in 400m buffer	1.01	(0.99, 1.02)	0.131
Commute route proportion in RBA	0.99	(0.98, 1.01)	0.410
Bikeability (median:IOR)	0.77	(, 0,,	
Home concentration in 400m buffer	1.00	(0.91, 1.12)	0.931
Work/study_concentration in 400m buffer	0.87	(0.79, 0.97)	0.011
Commute route concentration in RBA	0.86	(0.75, 0.98)	0.021

PA, Physical Activity, MVPA, Moderate-to-Vigorous Physical Activity, VPA, Vigorous Physical Activity, BMI, Body Mass Index. There are missing data in: Perceived stress (13; 1.65%), Country of brith (1; 0.13%), People living with in household (1; 0.13%), Employed people in household (4; 0.51), Children in household (2; 0.25%), Children <3 years old in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂ (20; 2.54%).

The GAM (Figure S1) showed that there is not statistical evidence to refuse linearity between bicycling commuting frequency (days/week) and perceived stress (score from 0 to 16). Multivariate logistic regression analyses showed a statistically-significant inverse relationship between bicycle commuting and perceived stress. Bicycle commuters had lower odds of being stressed compared to non-bicycle commuters [OR (95%CI) = 0.61 (0.46, 0.83)]. This relationship was remained when adjusted for confounders (individual and environmental determinants) and in the majority of sensitivity analyses (Table 3, Table S4). There was a statistically-significant inverse relationship between medium and high levels of bicycle commuting and perceived stress using non-bicycle commuters [OR (95%CI) = 0.34 (0.17,(0.65); OR (95%CI) = (0.50, (0.34, 0.71)] and low levels of bicycle commuting [OR (95%CI) = 0.28 (0.14, 0.59); OR (95%CI) = 0.42 (0.26, 0.68)] as a reference group. This statisticallysignificant relationship was remained when adjusting for individual and environmental determinants and with perceived stress at P75 and P90. Regarding bicycle commuting propensity, there was a statistically-significant inverse relationship between frequent bicycle commuters and perceived stress, using unwilling non-bicycle commuters [OR (95% CI) = 0.37(0.25, 0.54)] and infrequent bicycle commuters [(95%CI) = 0.39 (0.24, 0.62)] as a reference group. The statistically-significant relationship remained after adjusting for individual and environmental determinants and with perceived stress at P75 and P90. Also, there was a statistically-significant inverse relationship between willing non-bicycle commuters and perceived stress, using unwilling non-bicycle commuters [OR (95%CI) = 0.58 (0.38, 0.89)]]as a reference group. This relationship remained after adjusting for individual and environmental determinants, but not for perceived stress at P75 and P90.

There was no statistically-significant interaction between sex and bicycle commuters in TAPAS Travel Survey sample.

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 Table 3. Relationship between bicycle commuting and perceived stress (median) of participants.

			Perceived stress										
Variable	OR Unadjusted (95% CI)		p-value	OR Adjusted ^a (95% CI)		p-value	OR	Adjusted ^b 95% CI)	p-value	OR Adjusted ^c (95% CI)		p-value	
All sample (771)							```	, i			· · · · ·		
Bicycle commuting status													
Non-bicycle commuters	1.00			1.00			1.00			1.00			
Bicycle commuters	0.61	(0.46, 0.83)	0.001	0.62	(0.46, 0.85)	0.003	0.64	(0.47, 0.89)	0.007	0.70	(0.50, 0.97)	0.032	
Bicycle commuting levels		· · · · ·											
Non-bicycle commuters (0 days)	1.00			1.00			1.00			1.00			
Low bicycle commuting (1-3 days)	1.18	(0.77, 1.82)	0.445	1.22	(0.78, 1.91)	0.386	1.25	(0.79, 1.98)	0.332	1.33	(0.84, 2.12)	0.222	
Medium bicycle commuting (4 days)	0.34	(0.17, 0.65)	0.001	0.30	(0.15, 0.59)	< 0.001	0.30	(0.15, 0.60)	0.001	0.33	(0.17, 0.66)	0.002	
High bicycle commuting (>=5 days)	0.50	(0.34, 0.71)	< 0.001	0.52	(0.36, 0.76)	0.001	0.54	(0.37, 0.80)	0.002	0.58	(0.39, 0.87)	0.008	
Bicycle commuting propensity													
Unwilling Non-bicycle commuters	1.00			1.00			1.00			1.00			
Willing Non-bicycle commuters	0.58	(0.38, 0.89)	0.012	0.61	(0.39, 0.94)	0.025	0.59	(0.38, 0.92)	0.019	0.61	(0.39, 0.94)	0.027	
Infrequent Bicycle commuters	0.96	(0.60, 1.51)	0.846	0.99	(0.61, 1.61)	0.978	1.01	(0.62, 1.64)	0.978	1.08	(0.66, 1.78)	0.759	
Frequent Bicycle commuters	0.37	(0.25, 0.54)	< 0.001	0.38	(0.26, 0.56)	< 0.001	0.39	(0.26, 0.58)	< 0.001	0.42	(0.28, 0.64)	< 0.001	
Bicycle commuters sample (387)													
Bicycle commuting levels													
Low bicycle commuting (1-3 days)	1.00			1.00			1.00			1.00			
Medium bicycle commuting (4 days)	0.28	(0.14, 0.59)	0.001	0.23	(0.11, 0.50)	< 0.001	0.23	(0.10, 0.49)	< 0.001	0.22	(0.10, 0.49)	< 0.001	
High bicycle commuting (>=5 days)	0.42	(0.26, 0.68)	< 0.001	0.42	(0.25, 0.70)	0.001	0.42	(0.25, 0.70)	0.001	0.42	(0.25, 0.70)	0.001	
Bicycle commuters propensity													
Infrequent (1-3 days)	1.00			1.00			1.00			1.00			
Frequent (>=4 days)	0.39	(0.24, 0.62)	< 0.001	0.37	(0.23, 0.61)	< 0.001	0.37	(0.23, 0.60)	< 0.001	0.37	(0.22, 0.60)	< 0.001	
Non-bicycle commuters sample (384)													
Non-bicycle commuters													
Unwilling	1.00			1.00			1.00			1.00			
Willing	0.58	(0.38, 0.89)	0.012	0.59	(0.38, 0.91)	0.017	0.56	(0.36, 0.88)	0.011	0.58	(0.37, 0.91)	0.017	

^{*}Adjusted by Sex, Country of birth, Employed people in household, Chronic disease, ^bAdjusted by Sex, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). ^cAdjusted by Sex, Country of birth, Employed people in household, Chronic disease, Self-perceived health, MVPA, Public bicycle stations at work/study, Bikeability at work/study, Bikeability at commute route.

DISCUSSION

Summary of results

There was a statistically-significant inverse relationship between bicycle commuting and perceived stress. Bicyclist commuters who bicycled four or more days per week had lower odds of being stressed, and this relationship remained statistically-significant with sensitivity analyses.

Comparison with previous studies

To our knowledge, this study is the first to assess if there is a relationship between bicycle commuting and perceived stress. A few studies have focused on the relationship between active commuting and mental health,(4–6) but the relationship is still quite unclear. One study found a positive association between active commuting (walking and cycling) and well-being(4), and another with better mental health in men.(6) Moreover, Humphreys(5) found a positive relationship between time spent actively commuting and levels of physical well-being, but not with mental well-being. The relationship between physical activity and mental health has been studied more. It has been suggested that physical activity could reduce anxiety and improve physical self-perceptions and global self-esteem,(11) and it has been associated with lower depressive symptomatology and greater emotional well-being. (34) Our results are consistent with the general idea that active commuting is associated with better mental health, but does not support physical activity as a mediator in this relationship. Our analyses did not show a statistically-significant relationship between reported levels of PA and perceived stress.

Qualitative research suggested that choice of travel mode may affect well-being.(14) The quantity of public bicycle (*Bicing*) stations and the amount of greenness has been related to bicycle commuting propensity,(19) which seems to be related with the idea of commuting on a bicycle is more likely to give people the opportunity to "enjoy" or "experience" greenness than commuting on public transport or a car. At the same time, the availability of green space close to one's home has been shown to be related to better perceived general health.(35) Therefore, it seems that perceptual and environmental factors related to bicycle commuting could affect perceived stress, rather than the physical activity levels. This general idea is consistent with our results which show an inverse relationship between perceived stress and bicycle-friendly environments (public bicycle and bikeability levels) in work/study address area and the commute route. Also, our results showed that general attitude might have a role in this relationship, as we have seen that those willing non-bicycle commuters, compared to unwilling non-bicycle commuters, were less stressed. But this remained quite unclear as the relationship disappears in the sensitivity analyses.

Limitations and strengths

Our study had some limitations. Firstly, our study used a cross-sectional design, which is not well-suited to assess the direction of causation and we cannot exclude reverse causality or residual confounding. Secondly, our measurement method may be prone to information bias. With the questionnaire data we could have misclassification error of bicycle commuting and PA because of the data being self-reported. Because of that, the potential mediation by PA could be under-estimated.(36) The TAPAS Travel Survey only measured levels of PA without differentiating between types of PA (work, travel, recreational). Furthermore, the modification of the 5-point PSS-4 Likert scale into a 4-point Likert scale could incorrectly-estimate the perceived stress.

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This study had several strengths, too. The study had high internal validity, with a good representation of bicycle commuters. Related to subjects' characteristics, the TAPAS Travel Survey sample is representative of Barcelona's population from the socio-demographic point of view. It was compared with data from the Catalan government's Barcelona Active Population Survey (Statistics and information service, Catalan government 2011) and no statistically-significant differences between subjects' deprivation index and home and work population density in both surveys were found.(3,19) Finally, our study in a southern European city has added evidence in a different context than the current literature on these issues.

Future research

Our findings underscored the need for future research. There is a need to obtain a clear understanding of the relationship between the bicycle commuting and perceived stress in longitudinal studies. It is likely that other factors could mediate the relationship between these two variables, especially those related to environmental determinants and personal attitudes. Further work related to determinants of bicycle commuting and perceived stress is needed.

CONCLUSIONS

We found that healthy, adult bicycle commuters had lower stress than commuters of other transport modes. Also, bicycle commuters who bicycled four or more days per week had lower stress than those who bicycled less than that. Environmental determinants such as the number of public bicycle stations and bikeability, and also personal attitudes seem to have an influence on this relationship. Our findings should be considered by decision-makers when

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promoting bicycle commuting as a daily routine, to reduce stress levels and improve public health and well-being.

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COMPETING INTERESTS

No conflicts of interest were reported by the authors of this paper.

AUTHOR'S CONTRIBUTION

IAP drafted this version of the paper and received input from all the authors. All authors read and commented on the paper and agreed with the final version.

DATA SHARING

Extra data is available by emailing the corresponding author (Ione Avila-Palencia:

ione.avila@isglobal.org).

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SUPPLEMENTARY MATERIAL

Table S1. PSS4 questions used in TAPAS Travel Survey

Q218. In the last month, ¿how many times have you feel you can't control important things in your life?

0	Never
1	Nearly never
2	Often
3	Ever
997	Don't Know
998	Refuse to Answer

Q219. In the last month, ¿how many times have you feel safety in your cleverness of take care of your own personal problems?

0	Never
1	Nearly never
2	Often
3	Ever
997	Don't Know
998	Refuse to Answer

- Q220. In the last month, ; how many times have you feel that around things go in harmony you're your life?
 - Never
 Nearly never
 Often
 Ever
 Don't Know
 Refuse to Answer
- *Q221.* In the last month, ¿how many times have you feel that difficulties are bigger than become impossible of overcome?
 - 0 Never
 - 1 Nearly never
 - 2 Often
 - 3 Ever
 - 997 Don't Know
 - 998 Refuse to Answer

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Table S2. Description of the individual and environmental determinants in TAPAS sample

for Bicycle commuting levels and Bicycle commuting propensity.

			ысусіе	commutir	ig ievels						Dicycle c	omnutin	ig propei	nsity					
Variables	(1	.ow 109)	Med (6	lium 5)	(22	gh (4)	p-value	Unwi (23	illing 30)	Wil (1	lling 60)	Infre (1	equent .09)	Free (2	quent (89)	p-val			
	n	%	n	%	n	%		n	%	n	%	n	%	n	%				
Outcome																			
Stressed (median)(Yes)	49	45.37	12	19.05	57	26.15	< 0.001	107	46.93	55	34.81	49	45.37	69	24.56				
Individual determinants																			
Age (median; IQR)	36	14	36	17	35	12	0.777	37	16	36	16	36	14	35	12				
Total PA – min/week (median;IQR)	494.99	435.00	454.99	330.01	484.99	440.00	0.567	364.99	390.01	404.99	420.00	494.99	435.00	480.00	405.01				
MVPA – min/week (median;IQR)	240.00	345.01	294.99	200.00	300.00	302.50	0.092	90.00	244.99	90.00	240.00	240.00	345.01	300.00	270.00				
VPA – min/week (median;IQR)	120.00	224.99	90.00	199.99	102.50	240.00	0.386	45.00	150.00	0.00	127.50	120.00	224.99	90.00	225.00				
Sex (Female)	49	44.95	33	50.77	94	41.96	0.446	151	65.65	83	51.88	49	44.95	127	43.94				
Country of birth (non-Spanish)	19	17.59	7	10.77	30	13.39	0.412	16	6.96	25	15.63	19	17.59	37	12.80				
Working status (Student)	17	15.60	10	15.38	24	10.71	0.364	24	10.43	29	18.13	17	15.60	34	11.76				
Education level (University studies completed or equivalent level education)	r 81	74.31	50	76.92	173	77.23	0.836	161	70.00	86	53.75	81	74.31	223	77.16				
Living with family/partner	88	80.73	48	75.00	172	76 79	0.622	192	92.49	135	84 38	88	80.73	220	76 39				
Employed people in household (>2)	69	63 30	35	55 56	145	64 73	0.410	152	66 09	109	68 99	69	63 30	180	62.72				
MEDEA index							0.627												
MEDEA Index	35	32.11	23	35 38	75	33.48	0.027	81	35.22	49	30.63	35	32 11	98	33.91				
1 st tertile (least deprived)	38	34.86	23	41 54	76	33.93		66	28.70	56	35.00	38	34.86	103	35.64				
	36	33.03	15	23.08	73	32.50		83	36.00	55	34.38	36	33.03	88	30.45				
3rd tertile (most deprived)	31	28.44	18	29.08	70	35.27	0.340	0/	40.87	57	35.85	31	28.44	07	33.68				
Children in household (Yes)	2	20.44	5	7.04	20	8 02	0.114	20	9 72	16	10.00	2	20.44	25	9 71				
Children <3 years in household (Yes)	42	2.75	27	1.54	112	50.45	0.122	20	0.75 20.12	50	21.25	43	2.75	140	0.71				
Self-perceived health (Very good/Excellent)	43	39.43	27	41.54	115	50.45	0.125	90	39.13	50	51.25	45	39.45	62	40.44				
BMI (Overweight/Obese)	25	22.94	14	21.54	49	21.88	0.969	73	31.88	51	32.08	25	22.94	05	21.8				
Chronic disease (Yes)	11	10.09	8	12.51	17	1.39	0.438	18	7.85	120	4.38	11	10.09	23	8.05				
Stress releasing (Agreement)	95	87.10	62	98.41	199	90.03	0.047	105	72.44 51.70	139	89.08	95	87.10	201	91.90				
Bicycle trip enjoyment (Agreement)	103	94.50	05	100.00	212	93.93	0.175	110	51.79	155	04./1	105	94.50	277	90.85				
Environmental determinants Commute distance, estimated (km) (median;IRQ)	3.36	2.81	3.14	2.14	2.86	1.99	0.044	3.89	2.88	3.93	2.70	3.36	2.81	2.98	2.12				
Public bicycle stations (median;IQR)																			
Home, count in 400m buff	4	3	5	3	5	3	0.492	4	3	3	3	4	3	5	3				
Work/study, count in 400m buff	5	4	6	3	5	4	0.124	4	4	5	5	5	4	5	3				
Greenness, NDVI [IQR, (median; IQR)]																			
Home, average of 400m buff	0.50	1.07	0.48	1.13	0.41	0.70	0.635	0.63	1.19	0.76	1.01	0.50	1.07	0.44	0.75				
Work/study, average of 400m buffer	0.35	1.02	0.27	0.57	0.35	0.98	0.136	0.38	1.05	0.41	1.08	0.35	1.02	0.32	0.87				
Commute route, average of RBA	0.69	1.12	0.54	0.56	0.68	0.88	0.322	0.72	1.28	0.70	1.16	0.69	1.12	0.66	0.83				
NO2, ppb (median;IQR)																			
Home, concentration in 400m buffer	74.75	29.71	79.15	24.02	80.11	24.36	0.186	76.56	26.10	73.47	25.00	74.75	29.71	80.11	24.40				
Work/study, concentration in 400m buffer	77.60	33.01	86.23	27.41	80.70	30.12	0.091	82.21	34.12	79.23	38.33	77.60	33.01	82.61	30.00				
Commute route, concentration in RBA	82.49	18.19	87.19	23.04	85.51	24.29	0.127	86.61	23.03	82.05	20.99	82.49	18.19	85.75	24.56				
Noise, >55dB (%) (median;IQR)																			
Home, proportion in 400m buffer	79.95	15.23	79.09	11.59	79.62	15.47	0.554	79.39	13.89	78.79	12.69	79.95	15.23	79.46	14.84				
Work/study, proportion in 400m buffer	83.92	23.69	81.36	21.45	80.83	22.22	0.468	80.14	22.52	80.85	24.54	83.92	23.69	80.90	21.94				
Commute route, proportion in RBA	78.54	11.93	73.15	12.48	77.31	13.02	0.057	76.78	10.84	77.57	10.63	78.54	11.93	76.50	13.37				
Bikeability (median;IQR)																			
Home, concentration in 400m buffer	6.63	2.30	6.73	1.66	6.70	1.67	0.330	5.97	2.30	5.92	2.35	6.63	2.30	6.72	1.72				
Work/study, concentration in 400m buffer	7.15	2.08	7.01	1.20	7.02	1.86	0.638	6.64	2.56	6.89	1.89	7.15	2.08	7.01	1.69				
Commute and a concentration in DDA	6.86	1 38	7 23	0.99	7 1 5	1 29	0.236	6 59	1.83	6 77	1 54	6.86	1 38	716	1 23				

ter oute, concentration in RBA 0.00 1.30 1.25 0.27 1.13 1.27 0.20 0.37 1.83 0.71 1.34 0.80 1.38 7.16 1.23 (0) PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; BMI, Body Mass Index. Data are n and %, unless otherwise noted. There are missing data in: Perceived stress (13; 1.65%), Country of birth (1; 0.13%), Living with family/partner (1; 0.13%), Employed people in household (4; 0.51), Children in household (2; 0.25%), Children <3years old in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂(20; 2.54%). ^aChi square test, instead of Age, Total PA, MVPA, VPA, and all the Environmental determinants (U Mann Whitney test).

Table S3. Sensitivity analyses looking the relationship between perceived stress (P75, P90)

and all the covariates.

Tailable OR (95% CI) p-value OR (95% CI) Individual determinants Age 1.00 (0.98, 1.02) 0.783 0.99 (0.97, 1.02) Total PA - min/week 1.00 (0.99, 1.00) 0.057 1.00 (0.99, 1.00) MVPA - min/week 1.00 (0.99, 1.00) 0.057 1.00 (0.99, 1.00) Sex (Female) 1.51 (1.04, 2.21) 0.031 1.78 (1.05, 2.43) Country of birth (non-Spanish) 1.19 (0.72, 0.5) 0.520 1.16 (0.52, 2.43) Education level (University studies completed or quivalent-level education) 0.74 (0.50, 1.09) 0.122 0.78 (0.46, 1.34) Living with familypartner 1.00 (0.62, 1.60) 0.987 0.94 (0.50, 1.77) Employed people in household (>2) 0.62 (0.42, 0.90) 0.012 0.73 (0.43, 1.22) MEDEA index 1.55 (0.97, 2.49) 0.065 1.85 (0.94, 3.66) Children in household (Yes) 0.56 0.56 0.52 0.51 0.57	Perceived stress (P90)					
Individual determinants Age 1.00 $(0.98, 1.02)$ 0.783 0.99 $(0.97, 1.02)$ Total PA - min/week 1.00 $(0.99, 1.00)$ 0.057 1.00 $(0.99, 1.00)$ MVPA - min/week 1.00 $(0.99, 1.00)$ 0.57 1.00 $(0.99, 1.00)$ Sex (Female) 1.51 $(1.04, 2.21)$ 0.031 1.78 $(1.05, 3.01)$ Country of birth (non-Spanish) 1.19 $(0.70, 2.05)$ 0.520 1.16 $(0.55, 2.43)$ Working status (Student) 1.61 $(0.98, 2.64)$ 0.060 1.05 $(0.50, 1.09)$ Education level (University studies completed or equivalent-level education) 0.74 $(0.50, 1.09)$ 0.122 0.78 $(0.46, 1.34)$ Living with family/partner 1.00 0.62 $(0.42, 0.90)$ 0.012 0.73 $(0.43, 1.22)$ MEDEA index 1.00 1.00 1.00 1.00 1.00 1.00 1.01 1.01 1.02 1.03 $(0.95, 2.44)$ 0.079 1.95 $(0.93, 3.85)$	p-value					
Individual determinants Age 1.00 $(0.98, 1.02)$ 0.783 0.99 $(0.97, 1.02)$ Total PA - min/week 1.00 $(0.99, 1.00)$ 0.057 1.00 $(0.99, 1.00)$ VPA - min/week 1.00 $(0.99, 1.00)$ 0.367 1.00 $(0.99, 1.00)$ VPA - min/week 1.00 $(0.99, 1.00)$ 0.367 1.00 $(0.99, 1.00)$ Sex (Female) 1.51 $(1.04, 2.21)$ 0.031 1.78 $(1.05, 3.01)$ Country of birth (non-Spanish) 1.19 $(0.70, 2.05)$ 0.520 1.16 $(0.55, 2.43)$ Working status (Student) 1.61 $(0.98, 2.64)$ 0.060 1.05 $(5.5, 2.43)$ Living with finally/partner 1.00 0.62 $(0.42, 0.90)$ 0.112 0.78 $(0.44, 1.34)$ Living with finally/partner 1.00 0.62 $(0.42, 0.90)$ 0.012 0.73 $(0.43, 1.22)$ MEDEA index 1.00 1.55 0.778 0.91 $(0.53, 1.56)$ Children 'a years in household (Yes) <th></th>						
Age1.00 0.98 , 1.02) 0.783 0.99 $(0.99, 1.00)$ MVPA - min/week1.00 $(0.99, 1.00)$ 0.057 1.00 $(0.99, 1.00)$ MVPA - min/week1.00 $(0.99, 1.00)$ 0.367 1.00 $(0.99, 1.00)$ VPA - min/week1.00 $(0.99, 1.00)$ 0.367 1.00 $(0.99, 1.00)$ Sex (Female)1.51 $(1.04, 2.21)$ 0.031 1.78 $(1.05, 3.01)$ Country of birth (non-Spanish)1.19 $(0.70, 2.05)$ 0.520 1.16 $(0.55, 2.43)$ Working status (Student)1.61 $(0.98, 2.64)$ 0.060 1.05 $(0.50, 2.19)$ Education level (University studies completed or equivalent-level education) 0.74 $(0.50, 1.09)$ 0.122 0.78 $(0.46, 1.34)$ Employed people in household (>2) 0.62 $(0.42, 0.90)$ 0.012 0.73 $(0.43, 1.22)$ MEDEA index1.001.001.001.001.002nd tertile (nost deprived)1.56 $(0.97, 2.49)$ 0.065 1.85 $(0.94, 3.66)$ Children in household (Yes)1.06 $(0.25, 1.27)$ 0.166 1.03 $(0.52, 1.47)$ BMI (Overweight/Obes)1.10 $(0.3, 1.55)$ 0.778 0.91 $(0.52, 1.47)$ BMI (Overweight/Obes)1.09 $(0.99, 3.28)$ 0.059 1.77 $(0.80, 3.90)$ Stress releasing (Agreement) 0.68 $0.44, 1.06$ 0.092 0.78 $(0.42, 1.42)$ Pavis model distance, estimated (km) 1.09 $(0.99, 1.18)$ 0.061	0.774					
Total PA - mm/week 1.00 $(0.99, 1.00)$ 0.057 1.00 $(0.99, 1.00)$ VPA - min/week 1.00 $(0.99, 1.00)$ 0.115 1.00 $(0.99, 1.00)$ VPA - min/week 1.00 $(0.99, 1.00)$ 0.367 1.00 $(0.99, 1.00)$ Sex (Female) 1.51 $(1.04, 2.21)$ 0.031 1.78 $(1.05, 3.01)$ Country of birth (non-Spanish) 1.19 $(0.70, 2.05)$ 0.520 1.16 $(0.55, 2.43)$ Working status (Student) 1.61 $(0.98, 2.64)$ 0.060 1.05 $(0.50, 2.19)$ Education level (University studies completed or equivalent-level education) 0.74 $(0.50, 1.09)$ 0.122 0.78 $(0.46, 1.34)$ Living with family/partner 1.00 0.62 $(0.42, 0.90)$ 0.012 0.73 $(0.43, 1.22)$ MEDEA index 1.35 $(0.97, 2.49)$ 0.065 1.85 $(0.94, 3.66)$ Children in household (Yes) 1.06 $0.72, 1.55$ 0.778 0.91 $(0.53, 1.47)$ Self-proceived health (Very good/Excellent) 0.60 $(0.40, 0.89)$ 0.056 1.03 <t< td=""><td>0.674</td></t<>	0.674					
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	0.775					
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Sex (Female) 1.51 $(1.04, 2.21)$ 0.031 1.78 $(1.05, 3.01)$ Country of birth (non-Spanish) 1.19 $(0.70, 2.05)$ 0.520 1.16 $(0.55, 2.43)$ Working status (Student) 1.61 $(0.98, 2.64)$ 0.060 1.05 $(0.50, 2.19)$ Education level (University studies completed or equivalent-level education) 0.74 $(0.50, 1.09)$ 0.122 0.78 $(0.46, 1.34)$ Living with family/partner 1.00 $(0.62, 1.60)$ 0.987 0.94 $(0.50, 1.77)$ Employed people in household (≥ 2) 0.62 $(0.42, 0.90)$ 0.012 0.73 $(0.43, 1.22)$ MEDEA index 1.53 $(0.95, 2.44)$ 0.079 1.95 $(0.99, 3.82)$ 3rd tertile (nost deprived) 1.56 $(0.72, 1.55)$ 0.778 0.911 $(0.53, 1.56)$ Children '3 years in household (Yes) 0.56 $(0.25, 1.27)$ 0.166 0.52 $(1.61, 70)$ Sters releasing (Agreement) 0.68 $(0.49, 1.35)$ 0.651 1.03 $(0.58, 1.82)$ Chronic disease (Yes) 1.77 $(0.98, 3.28)$ 0.05	0.728					
Country of birth (non-Spanish) 1.19 $0.70, 2.05$) 0.520 1.16 $(0.55, 2.43)$ Working status (Student) 1.61 $(0.98, 2.64)$ 0.060 1.05 $(0.50, 2.19)$ Education level (University studies completed or equivalent-level education) 0.74 $(0.50, 1.09)$ 0.122 0.78 $(0.46, 1.34)$ Living with family/partner 1.00 $0.62, 1.60)$ 0.987 0.944 $(0.50, 1.77)$ Employed people in household (>2) 0.62 $(0.42, 0.90)$ 0.012 0.73 $(0.43, 1.22)$ MEDEA index 1.00 1.00 1.00 1.00 1.00 2.03 $(0.53, 1.56)$ $(0.77, 2.49)$ 0.065 1.85 $(0.99, 3.82)$ 3rd tertile (most deprived) 1.56 $(0.97, 2.49)$ 0.065 1.85 $(0.94, 3.66)$ Children in household (Yes) 1.06 $(0.72, 1.55)$ 0.778 0.911 $(0.52, 1.47)$ BMI (Overweight/Obese) 1.10 $(0.73, 1.65)$ 0.665 1.03 $(0.52, 1.47)$ BMI (Overweight/Obese) 1.79	0.034					
Working status (Student) 1.61 $(0.98, 2.64)$ 0.060 1.55 $(0.50, 2.19)$ equivalent-level education) 0.74 $(0.50, 1.09)$ 0.122 0.78 $(0.46, 1.34)$ Employed people in household (>2) 0.62 $(0.42, 0.90)$ 0.012 0.78 $(0.46, 1.34)$ Ist ertile (least deprived) 0.62 $(0.42, 0.90)$ 0.012 0.73 $(0.43, 1.22)$ MEDEA index 1.00 1.00 1.00 1.00 1.00 2nd tertile (nost deprived) 1.56 $(0.97, 2.49)$ 0.065 1.85 $(0.94, 3.66)$ Children in bousehold (Yes) 1.66 $0.72, 1.55$ 0.778 0.91 $(0.53, 1.56)$ Children in bousehold (Yes) 0.56 $(0.25, 1.27)$ 0.166 0.52 $(0.41, 1.09)$ Self-perceived health (Very good/Excellent) 0.60 $0.40, 0.89$ 0.010 0.87 $(0.52, 1.47)$ BMI (Overweight/Obese) 1.10 $0.73, 1.65$ 0.655 1.03 $(0.52, 1.47)$ Bicycle trip enjoyment (Agreement)	0.696					
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Living with family/partner 1.00 $(0.62, 1.60)$ 0.987 0.94 $(0.50, 1.77)$ Employed people in household (>2) 0.62 $(0.42, 0.90)$ 0.012 0.73 $(0.43, 1.22)$ MEDEA index 1.00 1.00 1.00 1.00 2nd tertile (least deprived) 1.53 $(0.95, 2.44)$ 0.079 1.95 $(0.99, 3.82)$ 3rd tertile (most deprived) 1.56 $(0.97, 2.49)$ 0.065 1.85 $(0.94, 3.66)$ Children in household (Yes) 0.56 $(0.25, 1.27)$ 0.166 0.52 $(0.16, 1.70)$ Self-percived health (Very good/Excellent) 0.60 $(0.72, 1.55)$ 0.778 0.91 $(0.53, 1.66)$ Chronic disease (Yes) 1.10 $(0.73, 1.65)$ 0.665 1.03 $(0.58, 1.82)$ Chronic disease (Yes) 0.79 $0.98, 3.28$ 0.059 1.77 $(0.80, 3.90)$ Sters releasing (Agreement) 0.68 $0.44, 1.06$ 0.092 0.78 $(0.42, 1.42)$ Environmental determinants Intermineas Intermin 400m buf	0.370					
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Children in household (Yes) 1.06 $(0.72, 1.55)$ 0.778 0.91 $(0.53, 1.56)$ Children <3 years in household (Yes)	0.074					
Children <3 years in household (Yes) 0.56 $(0.25, 1.27)$ 0.166 0.52 $(0.16, 1.70)$ Self-perceived health (Very good/Excellent) 0.60 $0.40, 0.89$ 0.010 0.87 $(0.52, 1.47)$ BMI (Overweight/Obese) 1.10 $(0.73, 1.65)$ 0.665 1.03 $(0.58, 1.82)$ Chronic disease (Yes) 1.79 $(0.98, 3.28)$ 0.059 1.77 $(0.80, 3.90)$ Stress releasing (Agreement) 0.82 $(0.49, 1.35)$ 0.428 0.93 $(0.44, 1.42)$ Environmental determinants 0.99 $(0.99, 1.18)$ 0.061 1.03 $(0.91, 1.16)$ Public bicycle stations 0.99 $(0.92, 1.06)$ 0.761 0.93 $(0.88, 1.04)$ Work/study, count in 400m buffer 0.99 $(0.92, 1.06)$ 0.761 0.93 $(0.81, 1.31)$ Greenness, NDVI [IQR, (median; IQR)] 0.94 $(0.78, 1.13)$ 0.487 1.04 $(0.83, 1.31)$ Work/study, count in 400m buffer 0.94 $(0.78, 1.13)$ 0.487 1.04 $(0.83, 1.31)$ <t< td=""><td>0.743</td></t<>	0.743					
Self-perceived health (Very good/Excellent) 0.60 $(0.40, 0.89)$ 0.010 0.87 $(0.52, 1.47)$ BMI (Overweight/Obese) 1.10 $(0.73, 1.65)$ 0.665 1.03 $(0.58, 1.82)$ Chronic disease (Yes) 1.79 $(0.98, 3.28)$ 0.059 1.77 $(0.80, 3.90)$ Stress releasing (Agreement) 0.82 $(0.49, 1.55)$ 0.428 0.93 $(0.46, 1.89)$ Bicycle trip enjoyment (Agreement) 0.68 $(0.44, 1.06)$ 0.092 0.78 $(0.42, 1.42)$ Environmental determinants Commute distance, estimated (km) 1.09 $(0.99, 1.18)$ 0.061 1.03 $(0.91, 1.16)$ Public bicycle stations Home, count in 400m buffer 0.99 $(0.92, 1.06)$ 0.761 0.93 $(0.84, 1.04)$ Work/study, count in 400m buffer 0.95 $(0.89, 1.01)$ 0.088 0.95 $(0.87, 1.04)$ Greenness, NDVI [IQR, (median;IQR)] Home, average of 400m buffer 1.11 $(0.93, 1.31)$ 0.487 1.04 $(0.83, 1.31)$ Noz, pp (median;IQR) Home, concentration in 400m buffer 1.00 $(0.98, 1.01)$ 0.379 $(0.98,$	0.280					
BMI (Overweight/Obese) 1.10 $(0.73, 1.65)$ 0.665 1.03 $(0.58, 1.82)$ Chronic disease (Yes) 1.79 $(0.98, 3.28)$ 0.059 1.77 $(0.80, 3.90)$ Stress releasing (Agreement) 0.82 $(0.49, 1.35)$ 0.428 0.93 $(0.46, 1.89)$ Bicycle trip enjoyment (Agreement) 0.68 $0.444, 1.06$ 0.092 0.78 $(0.42, 1.42)$ Environmental determinants Commute distance, estimated (km) 1.09 $(0.99, 1.18)$ 0.061 1.03 $(0.91, 1.16)$ Public bicycle stations Home, count in 400m buffer 0.99 $(0.92, 1.06)$ 0.761 0.93 $(0.84, 1.04)$ Work/study, count in 400m buffer 0.95 $(0.89, 1.01)$ 0.088 0.95 $(0.87, 1.13)$ Home, average of 400m buffer 0.94 $(0.78, 1.13)$ 0.487 1.04 $(0.83, 1.31)$ Work/study, average of 400m buffer 1.10 $(0.98, 1.01)$ 0.254 0.99 $(0.95, 1.52)$ NO2, ppb (median; IQR) Home, concentration in 400m buffer 1.00 $(0.98, 1.01)$ 0.379 $(0.09, 1.01)$ $0.98, 1.01)$	0.603					
Chronic disease (Yes) 1.79 $(0.98, 3.28)$ 0.059 1.77 $(0.80, 3.90)$ Stress releasing (Agreement) 0.82 $(0.49, 1.35)$ 0.428 0.93 $(0.46, 1.89)$ Bicycle trip enjoyment (Agreement) 0.68 $(0.44, 1.06)$ 0.092 0.78 $(0.42, 1.42)$ Environmental determinants Commute distance, estimated (km) 1.09 $(0.99, 1.18)$ 0.061 1.03 $(0.91, 1.16)$ Public bicycle stations Home, count in 400m buffer 0.99 $(0.92, 1.06)$ 0.761 0.93 $(0.84, 1.04)$ Work/study, count in 400m buffer 0.99 $(0.92, 1.06)$ 0.761 0.93 $(0.84, 1.04)$ Work/study, average of 400m buffer 0.95 $(0.89, 1.01)$ 0.088 0.95 $(0.87, 1.29)$ Commute route, average of RBA 1.05 $(0.86, 1.27)$ 0.643 1.20 $(0.98, 1.01)$ NO2, ppb (median; IQR) Home, concentration in 400m buffer 1.00 $(0.98, 1.01)$ 0.379 1.00 $(0.98, 1.01)$ Nose, >55dB (%) (median; IQR) Home, proportion	0.922					
Stress releasing (Agreement) 0.82 $(0.49, 1.35)$ 0.428 0.93 $(0.46, 1.89)$ Bicycle trip enjoyment (Agreement) 0.68 $(0.44, 1.06)$ 0.092 0.78 $(0.42, 1.42)$ Environmental determinants Commute distance, estimated (km) 1.09 $(0.99, 1.18)$ 0.061 1.03 $(0.91, 1.16)$ Public bicycle stations Home, count in 400m buffer 0.99 $(0.92, 1.06)$ 0.761 0.93 $(0.84, 1.04)$ Work/study, count in 400m buffer 0.99 $(0.92, 1.06)$ 0.761 0.93 $(0.84, 1.04)$ Greenness, NDVI [IQR, (median;IQR)] Home, average of 400m buffer 1.11 $(0.93, 1.34)$ 0.254 0.99 $(0.75, 1.29)$ Commute route, average of RBA 1.05 $(0.86, 1.27)$ 0.643 1.20 $(0.95, 1.52)$ NO2, ppb (median;IQR) Home, concentration in 400m buffer 1.00 $(0.98, 1.01)$ 0.379 1.00 $(0.98, 1.00)$ Commute route, concentration in RBA 1.00 $(0.98, 1.01)$ 0.447 0.99 $(0.98, 1.01)$ Nois, >55dB (%) (median;IQR) Home, proportion in 400m buffer <td< td=""><td>0.160</td></td<>	0.160					
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Commute route, average of KDA 1.00 (0.90, 1.27) 0.045 1.20 (0.92, 1.22) NO2, ppb (median;IQR) 1.00 (0.98, 1.01) 0.379 1.00 (0.98, 1.01) Home, concentration in 400m buffer 0.99 (0.98, 1.01) 0.379 1.00 (0.98, 1.01) Work/study, concentration in 400m buffer 0.99 (0.98, 1.01) 0.447 0.99 (0.98, 1.00) Noise, >55dB (%) (median;IQR) Home, proportion in 400m buffer 1.01 (0.99, 1.02) 0.417 1.00 (0.98, 1.03) Work/study proportion in 400m buffer 1.00 (0.99, 1.02) 0.539 1.00 (0.98, 1.02)	0.119					
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Home, concentration in 400m buffer 1.09 $(0.53, 1.01)$ 0.575 1.09 $(0.98, 1.01)$ Work/study, concentration in 400m buffer 0.99 $(0.98, 1.00)$ 0.048 0.99 $(0.98, 1.00)$ Commute route, concentration in RBA 1.00 $(0.98, 1.01)$ 0.447 0.99 $(0.98, 1.00)$ Noise, >55dB (%) (median;IQR) Home, proportion in 400m buffer 1.01 $(0.99, 1.02)$ 0.417 1.00 $(0.98, 1.03)$ Work/study, proportion in 400m buffer 1.00 $(0.99, 1.02)$ 0.539 1.00 $(0.98, 1.02)$	0 738					
Work/study, concentration in 400m buffer 0.99 (0.93, 1.00) 0.99 (0.97, 1.00) Commute route, concentration in RBA 1.00 (0.98, 1.01) 0.447 0.99 (0.97, 1.00) Noise, >55dB (%) (median;IQR) 1.01 (0.99, 1.02) 0.417 1.00 (0.98, 1.03) Work/study proportion in 400m buffer 1.01 (0.99, 1.02) 0.417 1.00 (0.98, 1.03)	0.087					
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Work/study, proportion in 400m buffer 1.00 (0.99, 1.02) 0.539 1.00 (0.98, 1.02)	0 8 1 4					
WORKSHRY INDODUDING DITLEF 1.00 10.77, 1.021 0.007 100 10 76 1021	0.829					
Commute south responsible in PDA $100(0.98102) = 0.854 = 101(0.08104)$	0.422					
Commute route, proportion in KBA 1.00 (0.26, 1.02) 0.034 1.01 (0.26, 1.04)	0.422					
Bikeability (median; IQK) $II = 0.05 (0.24 \pm 1.0) = 0.528 = 0.02 (0.77 \pm 0.0)$	0 225					
$ \begin{array}{cccccc} \text{nome, concentration in 400m buffer} & 0.70 & (0.64, 1.10) & 0.326 & 0.92 & (0.74, 1.09) \\ \text{Weak/study, concentration in 400m buffer} & 0.90 & (0.70, 1.02) & 0.007 & 0.92 & (0.74, 1.05) \\ \end{array} $	0.525					
work/study, concentration in 400m putter $0.70 (0.77, 1.02) = 0.057 = 0.86 (0.74, 1.03)$	0.020					

PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; BMI, Body Mass Index. There are missing data in: Perceived stress (13; 1.65%), Country of birth (1; 0.13%), People living with in household (1; 0.13%), Employed people in household (4; 0.51), Children in household (2; 0.25%), Children <3 years old in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂ (20; 2.54%).

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Figure S1. GAM assessing linearity between bicycle commuting (days/week) and perceived stress (score from 0 to 16). p-value= 0.3304.



Table S4. Sensitivity analyses looking the relationship between bicycle commuting (Bicycle commuting status, Bicycle commuting

levels, Bicycle commuting propensity) and perceived stress (P75, P90).

	0.0	Unadinated		0	D A dimeta d ^a	Perceived	stress (P75	5) A dimetad ^b		01	Adimated		0.0	Unadinated		0.0	Adimated	rerceived s	ress (P9	U) D. A dimoto d ^b		CP.	A dimetad ^c	
arrabic	OR (Unadjusted 95% CI)	p-value	UI OI	(95% CI)	p-value	06	Adjusted 95% CI)	p-value	OR (Adjusted 95% CI)	p-value	OR (Unadjusted 95% CI)	p-value	(9 (9	95% CI)	p-value	01	95% CI)	p-value	ок (9	Adjusted 95% CI)	p-
All sample (771)	Ì						```			```														
Bicycle commuting status																								
Non-bicycle commuters	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
Bicycle commuters	0.51	(0.35, 0.75)	0.001	0.50	(0.34, 0.75)	0.001	0.54	(0.36, 0.82)	0.004	0.58	(0.38, 0.88)	0.011	0.51	(0.30, 0.87)	0.014	0.53	(0.31, 0.91)	0.020	0.49	(0.28, 0.85)	0.012	0.53	(0.30, 0.95)	
Bicycle commuting levels																								
Non-bicycle commuters (0 days)	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
Low bicycle commuting (1-3 days)	1.06	(0.64, 1.76)	0.832	1.04	(0.62, 1.76)	0.869	1.10	(0.65, 1.87)	0.730	1.14	(0.66, 1.95)	0.639	1.23	(0.64, 2.34)	0.537	1.26	(0.65, 2.44)	0.493	1.17	(0.60, 2.29)	0.650	1.22	(0.61, 2.41)	
Medium bicycle commuting (4 days)	0.18	(0.05, 0.58)	0.004	0.16	(0.05, 0.52)	0.002	0.16	(0.05, 0.54)	0.003	0.18	(0.05, 0.59)	0.005	0.13	(0.02, 0.99)	0.049	0.13	(0.02, 0.93)	0.043	0.12	(0.02, 0.89)	0.038	0.13	(0.02, 0.98)	
High bioxels commuting (>=5 days)	0.39	(0.24, 0.64)	< 0.001	0.39	(0.24, 0.66)	< 0.001	0.43	(0.25, 0.73)	0.002	0.46	(0.27, 0.78)	0.004	0.31	(0.14, 0.67)	0.003	0.33	(0.15, 0.72)	0.005	0.30	(0.13, 0.66)	0.003	0.32	(0.14, 0.73)	
Biovele commuting propensity																								
Unwilling Non-biovale commuters	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
Willing Non-biovele commuters	0.64	(0.39,1.06)	0.085	0.67	(0.40, 1.13)	0 132	0.64	(0.38-1.08)	0.095	0.66	(0.39, 1.10)	0.113	0.62	(0.31, 1.24)	0 179	0.67	(0 33 1 34)	0.258	0.66	(0.33, 1.34)	0 254	0.68	(0.34 1.38)	
winning Non-bicycle commuters	0.89	(0.52, 1.53)	0.682	0.89	(0.51, 1.56)	0.691	0.97	(0.52, 1.62)	0.773	0.00	(0.54, 1.70)	0.881	1.03	(0.52, 2.05)	0.926	1.08	(0.53, 2.19)	0.825	1.00	(0.49, 2.04)	0.997	1.05	(0.51, 2.17)	
Infrequent Bicycle commuters	0.29	(0.17, 0.48)	<0.001	0.29	(0.17, 0.48)	<0.001	0.31	(0.18, 0.52)	<0.001	0.32	(0.19, 0.56)	<0.001	0.23	(0.11.0.49)	<0.001	0.24	(0.11, 0.52)	<0.001	0.22	(0.10, 0.49)	<0.001	0.24	(0.11, 0.54)	
Frequent Bicycle commuters	0.29	(0.17, 0.48)	~0.001	0.29	(0.17, 0.48)	~0.001	0.51	(0.18, 0.52)	~0.001	0.52	(0.19, 0.50)	~0.001	0.25	(0.11, 0.49)	~0.001	0.24	(0.11, 0.52)	~0.001	0.22	(0.10, 0.49)	~0.001	0.24	(0.11, 0.54)	
Sicycle commuters sample (387)																								
Bicycle commuting levels	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
Low bicycle commuting (1-3 days)	0.17	(0.05, 0.59)	0.005	0.15	(0.04.0.51)	0.002	0.15	(0.04.0.51)	0.002	0.14	(0.04.0.51)	0.002	1.00	(0.01.0.95)	0.024	0.10	(0.01.0.79)	0.020	0.10	(0.01.0.78)	0.020	0.00	(0.01.0.75)	
Medium bicycle commuting (4 days)	0.17	(0.05, 0.58)	0.005	0.15	(0.04, 0.51)	0.003	0.15	(0.04, 0.51)	0.003	0.14	(0.04, 0.51)	0.003	0.11	(0.01, 0.85)	0.034	0.10	(0.01, 0.78)	0.028	0.10	(0.01, 0.78)	0.028	0.09	(0.01, 0.75)	
High bicycle commuting (>=5 days)	0.37	(0.20, 0.69)	0.002	0.37	(0.20, 0.70)	0.002	0.37	(0.19, 0.70)	0.002	0.57	(0.19, 0.70)	0.002	0.25	(0.10, 0.62)	0.005	0.25	(0.10, 0.62)	0.005	0.24	(0.09, 0.60)	0.002	0.24	(0.09, 0.60)	
3icycle commuters propensity																								
Infrequent (1-3 days)	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
Frequent (>=4 days)	0.32	(0.18, 0.59)	< 0.001	0.31	(0.17, 0.58)	< 0.001	0.31	(0.17, 0.58)	< 0.001	0.31	(0.17, 0.58)	< 0.001	0.22	(0.09, 0.53)	0.001	0.21	(0.09, 0.52)	0.001	0.21	(0.08, 0.50)	0.001	0.20	(0.08, 0.50)	
Exposure Non-bicycle commuters sampl	e (384)																							
Ion-bicycle commuters																								
Unwilling	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
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STROBE Statement-checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Reported in page
Title and	1	(a) Indicate the study's design with a commonly used term in the title or the	Page 2
abstract		abstract	C
		(b) Provide in the abstract an informative and balanced summary of what	Page 2
		was done and what was found	C
Introduction			
Background/rati	2	Explain the scientific background and rationale for the investigation being	Pages 3, 4
onale		reported	-
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 4
Methods			
Study design	4	Present key elements of study design early in the paper	Page 4
Setting	5	Describe the setting, locations, and relevant dates, including periods of	Pages 4, 5
6		recruitment, exposure, follow-up, and data collection	
Participants	6	(a) Cohort study—Give the eligibility criteria, and the sources and methods	Pages 4, 5
F		of selection of participants. Describe methods of follow-up	
		<i>Case-control study</i> —Give the eligibility criteria, and the sources and	
		methods of case ascertainment and control selection. Give the rationale for	
		the choice of cases and controls	
		<i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and	
		methods of selection of participants	
		(b) Cohort study—For matched studies, give matching criteria and number	_
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		Crease control study. For metabod studies give metabing criterie and the	
		Case-control study—For matched studies, give matching criteria and the	
X7 · 11	7	number of controls per case	D 5 (7
Variables	1	Clearly define all outcomes, exposures, predictors, potential confounders,	Pages 5, 6, 7,
		and effect modifiers. Give diagnostic criteria, if applicable	8
Data sources/	8*	For each variable of interest, give sources of data and details of methods of	Pages 5, 6, 7,
measurement		assessment (measurement). Describe comparability of assessment methods	8
		if there is more than one group	
Bias	9	Describe any efforts to address potential sources of bias	Pages 4, 5
Study size	10	Explain how the study size was arrived at	Page 8, in
			previous
			papers
Quantitative	11	Explain how quantitative variables were handled in the analyses. If	Pages 5, 6, 7,
variables		applicable, describe which groupings were chosen and why	8
Statistical	12	(a) Describe all statistical methods, including those used to control for	Page 8
methods		confounding	
		(b) Describe any methods used to examine subgroups and interactions	Page 8
		(c) Explain how missing data were addressed	Page 8
		(d) Cohort study—If applicable, explain how loss to follow-up was	Page 8
		addressed	-
		<i>Case-control study</i> —If applicable, explain how matching of cases and	
		controls was addressed	
		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking	

Continued on next page

Results			Reported in page
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers	In previous
		potentially eligible, examined for eligibility, confirmed eligible, included in	papers
		the study, completing follow-up, and analysed	
		(b) Give reasons for non-participation at each stage	In previous
			papers
		(c) Consider use of a flow diagram	In previous
			papers
Descriptive	14*	(a) Give characteristics of study participants (eg demographic, clinical, social)	Pages 8, 9, 10
data		and information on exposures and potential confounders	
		(b) Indicate number of participants with missing data for each variable of	Pages 8, 9, 10
		interest	
		(c) Cohort study—Summarise follow-up time (eg, average and total amount)	-
Outcome data	15*	Cohort study—Report numbers of outcome events or summary measures over	-
		time	
		Case-control study—Report numbers in each exposure category, or summary	-
		measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary	Pages 9,11
		measures	
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted	Pages 12, 13
		estimates and their precision (eg, 95% confidence interval). Make clear which	
		confounders were adjusted for and why they were included	
		(b) Report category boundaries when continuous variables were categorized	Pages 6, 7
		(c) If relevant, consider translating estimates of relative risk into absolute risk	-
		for a meaningful time period	
Other analyses	17	Report other analyses done-eg analyses of subgroups and interactions, and	Page 12,
		sensitivity analyses	supplementary
			material
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias	Pages 15, 16
		or imprecision. Discuss both direction and magnitude of any potential bias	
Interpretation	20	Give a cautious overall interpretation of results considering objectives,	Pages 14, 15,
		limitations, multiplicity of analyses, results from similar studies, and other	16, 17
		relevant evidence	
Generalisability	21	Discuss the generalisability (external validity) of the study results	Pages 15, 16
Other informatio	on		
Funding	22		D 10
Funding	22	Give the source of funding and the role of the funders for the present study	Page 19

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at

http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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THE RELATIONSHIP BETWEEN BICYCLE COMMUTING AND PERCEIVED STRESS: A CROSS-SECTIONAL STUDY

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1 2		
- 3 4 5	1	THE RELATIONSHIP BETWEEN BICYCLE COMMUTING
6 7	2	AND PERCEIVED STRESS: A CROSS-SECTIONAL STUDY
8 9	3	Ione Avila-Palencia, MPH ^{1, 2, 3} ; Audrey de Nazelle, PhD ⁴ ; Tom Cole-Hunter, PhD ⁵ ; David
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ABSTRACT Introduction: Active commuting -walking and bicycling for travel to and/or from work or educational addresses- may facilitate daily, routine physical activity. Several studies have investigated the relationship between active commuting and commuting stress, but there are no studies examining the relationship between bicycle commuting and perceived stress, or studies that account for environmental determinants of bicycling commuting and stress. The current study evaluated the relationship between bicycle use for commuting among working or studying adults in a dense urban setting and perceived stress. Methods: A cross-sectional study was performed with 788 adults who regularly travelled to work or study locations in Barcelona, Spain, excluding those who only commuted on foot. Participants responded to a comprehensive telephone survey concerning their travel behaviour from June 2011 through to May 2012. Participants were categorised as either bicycle

13 commuters or non-bicycle commuters, and based on the Perceived Stress Scale (PSS-4), as

14 stressed or non-stressed. Multivariate Poisson regression with robust variance models of stress

15 status based on bicycling exposure, adjusting for potential confounders, were estimated.

Results: Bicycle commuters had significantly lower risk of being stressed [RR (95%CI) =

17 0.73 (0.60, 0.89)]. Bicycle commuters who bicycled four or more days per week had lower

18 risk of being stressed than those who bicycled less than four days. This relationship remained

19 statistically significant after adjusting for individual and environmental confounders, and

20 when using a different cut-off of perceived stress.

Conclusions: Stress reduction may be an important consequence of routine bicycle use and
 should be considered by decision makers as another potential benefit of its promotion.
2 3	1	STRENGHTS AND LIMITATIONS OF THIS STUDY
4 5 6	2	• The study had high internal validity, with a good representation of bicycle commuters.
7 8	3	• The study was conducted in Barcelona (a southern European city), adding evidence in
9 10	4	a different context than the current literature on these issues.
11 12	5	• The TAPAS Travel Survey sample is representative of Barcelona's population, taking
13 14 15	6	into account home neighbourhood deprivation and home and work population density.
15 16 17	7	• The study used a cross-sectional design, which is not well-suited to assess the
18 19	8	direction of causation.
20 21	9	• Using questionnaire data we could have misclassification error (information bias) of
22 23	10	bicycle commuting and physical activity because of the data being self-reported.
26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50		
50 51 52 53 54 55 56 57 58 59 60		For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml

INTRODUCTION

Walking and bicycling for transport is increasingly being promoted due to its potential for increasing physical activity (PA) levels in the general population (1-3). Active commuting – walking and bicycling for travel to and/or from work or educational addresses - has been associated with multiple health benefits from reductions to cardiovascular risk (4,5), lowering of body weight (2,5), improvement of fitness, reduced risk of diabetes (3), to higher levels of physical and mental well-being(6,7). Specifically, bicycle commuting has been inversely associated with all-cause mortality among both men and women in all age groups(8) and it seems to be likely to improve the health-related quality of life in previously untrained healthy adults(9). Active commuting has been shown to have other societal benefits such as helping reduce air pollution, greenhouse gas emissions, and noise, and improving social interaction(10).

Perceived stress is a global and comprehensive stress construct that refers to the interaction between the individual and the environment in the presence of a stressor(11). The perception of an event as stressful can result in a range of physiological, behavioural, and psychological changes, and can lead to cardiovascular disease, increased negative affect, lowered self-esteem, and lowered feelings of control. Hence, it is possible that mental health outcomes such as anxiety disorders and depression can be manifestations of chronic, perceived stress(12). Furthermore, others have suggested gender differences in stress-related variables. Women seem to be more physiologically reactive to social rejection challenges(13), are more likely to have daily stress, and be more impacted by life events(14).

24 Some literature recognises commuting as a potential source of stress(15); however, active

25 commuters have been shown to have higher levels of satisfaction, lower stress, higher

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relaxation and a heightened sense of freedom compared to car drivers.(16–18). Recent qualitative research has suggested that commuting can be perceived as a relaxing or transitional time between home and work life, which can also be about enjoying pleasant landscape, nature and wildlife(19). Emerging literature has highlighted the relevance of positive natural and built environment to increase bicycle commuting and to improve mental health outcomes. Bicycle lane connectivity, bikeability, separation of bicycling from other traffic, high population density, short trip distance, proximity of a cycle path, green space and also walkability have been suggested as determinants of bicycling(20–24). Green space has also been associated with better self-perceived general health and better mental health(25,26). Several studies have examined the relationship between active commuting and commuting stress (stress directly related with the act of commuting)(17,18,27,28), but none of them have studied the relationship between adult bicycle commuters and perceived stress, nor taking into

14 account environmental determinants. Moreover, most studies of active commuting benefits on

15 mental health have been conducted in North America or Northwest Europe, where the urban

16 design tends to be less dense than many parts of the world(6,7,17,28–30). Consequently, a

17 need exists to understand the relationship between bicycle commuting and perceived stress,

18 particularly in dense urban environments.

20 The current study aimed to evaluate the relationship between bicycle commuting among the

21 working or studying adult population and perceived stress in a dense urban setting.

1 MATERIALS AND METHODS

2 Study population

This cross-sectional study was based on participants from the Transportation, Air Pollution and Physical ActivitieS (TAPAS) Travel Survey. TAPAS is a relatively large study aimed at investigating the risks and benefits of active commuting. Participant recruitment was conducted by trained interviewers on the streets of Barcelona city between June 2011 and May 2012. To ensure adequate geographic coverage, a total of 40 random points (four random points within each of the ten city districts across Barcelona) were sampled. Adult bicycle commuters and non-bicycle commuters were asked in the street to answer a few screening questions, and those who fulfilled the inclusion criteria (being older than 18 years of age; living in Barcelona city since 2006 or earlier; working or going to school in Barcelona city; being healthy enough to ride a bicycle for 20 minutes; having a commute distance greater than a 10-minute walk; and using at least one mode of transport other than walking to commute) were invited to respond to a telephone survey. Bicycle commuters were oversampled to ensure enough bicycle commuters in the study. Those solely commuting on foot were excluded as the main interest was in the contrast between motorized modes (private and public transportation) and the bicycle. Of the 18469 participants approached across the forty sampling random points, 6701 agreed to answer screening questions. Of these, 1508 met the inclusion criteria, and 871 participants completed the survey. After survey responses were checked by the research team, 815 still fulfilled the inclusion criteria and 789 had geocodable home address. After excluding one PA outlier (total of all walking, moderate and vigorous time variables >960 minutes/day), 788 participants remained. Further details on the recruitment is given elsewhere(31).

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1	The study protocol was approved by the Clinical Research Ethical Committee of the Parc de
2	Salut Mar (CEIC-Parc de Salut Mar), and written informed consent was obtained from all
3	participants.
4	
5	Bicycle commuting
6	The TAPAS Travel Survey assessed the regular use of transport modes(32) and the bicycle
7	use(33). Participants who indicated using a bicycle (private or from public bicycle sharing
8	system) to go to work or school at least once the week prior to survey administration were
9	classified as "bicycle commuters". Participants who did not commute by bicycle in the week
10	prior to survey administration were classified as "non-bicycle commuters".
11	
12	As part of the sensitivity analyses, commuting behaviour was further classified according to
13	bicycle commuting levels and bicycle commuting propensity(24). Bicycle commuting levels
14	classification was based on the days of bicycle commuting in the week prior to survey
15	administration: "low" being three days or fewer, "medium" for four days, and "high" for five
16	or more days. This measure could be interpreted as a proxy of bicycle commuting frequency.
17	Bicycle commuting propensity classification took into account both frequency and
18	willingness to commute by bicycle: the "bicycle commuters" were further classified as
19	"frequent" (four or more days) or "infrequent" (three or less days), and the "non-bicycle
20	commuters" were classified as "willing" or "unwilling". The "willing" group were those
21	"non-bicycle commuters" who indicated bicycling as "never or nearly never" their general
22	transport mode, but who also indicated that they would consider bicycle commuting in
23	Barcelona (they answered positively to "considering costs, travelling time, comfort and
24	safety, how ready would you be to use the bicycle/Bicing (public bicycle-sharing system) for
25	your trip to work or education centre?"). The "unwilling" group were those "non-bicycle

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commuters" who indicated "never or nearly never" bicycling for travel and indicated that they
 would not consider bicycle commuting in Barcelona by answering negatively to the above
 question. More details of the bicycle commuting propensity classification are given
 elsewhere(24). This measure was included in the analysis to assess the effect of being willing
 to commute by bicycle in perceived stress.

7 Perceived stress

The last four questions of the TAPAS Travel Survey were the short version of Perceived Stress Scale (PSS-4)(11), which is a well-validated psychological instrument to measure the degree to which situations in one's life over the past month are appraised as stressful. The instrument contains four statements, which measure how unpredictable, uncontrollable, and overloaded respondents feel that their lives are (Table S1). The higher the score on the PSS-4 (from 0 to 16), the greater the respondent perceives that their demands exceed their ability to cope. There are no cut-off scores. Instead, an individual's score is compared to a normative value(34). In the TAPAS Travel Survey the 5-point Likert scale was modified to a 4-point Likert scale, removing the midpoint option for consistency with other questions in the survey, as all other questions used a 4-point Likert scale. The sample did not have high levels of perceived stress (Table S2); therefore, for an easier interpretation participants with a PSS-4 score higher than 3 (median of the total sample) were classified as "stressed", and those equal or lower than 3 were classified as "non-stressed". The sensitivity of our results to this choice was examined further in sensitivity analyses by classifying the respondents with PSS-4 scores in the 75th percentile (P75) and above (a score higher than 4) and in the 90th percentile (P90) and above (a score of 6 and above) as stressed and all others as non-stressed.

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1 **Other explanatory measures**

Individual determinants of bicycle commuting and perceived stress such as physical activity 3 levels(35), socio-demographic variables, and work or school addresses were also derived from 4 the TAPAS Travel Survey to be used as potential confounders. In addition, the MEDEA 5 Index (Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómicas y 6 Ambientales, in Spanish; Environmental and socioEconomic Inequalities in Mortality in small 7 Spanish areas, translated to English) was used as an area deprivation indicator assigned to 8 each participants' address. MEDEA measures deprivation at the census tract level based on 9 five domains including percentage of manual workers, temporary workers, total population 10 with low education, young population with low education, and unemployment(36). 11 12 Environmental determinants of bicycle commuting and perceived stress within a 400m buffer 13 surrounding home and work/study addresses, and a Route-By-Area (RBA) surrounding 14 predicted commute routes, were calculated to be used as potential confounders too. The 15 number of public bicycle stations within a 400m buffer surrounding home and work/study 16 addresses was calculated based on information from the Ajuntament de Barcelona -17 Informació de Base i Cartografia (IBC) (Barcelona City Council – Basic information and 18 mapping). Greenness was calculated as a mean in Normalized Difference Vegetation Index 19 (NDVI) via satellite imagery (LANDSAT 4 and 5, NASA). Mean NO₂ levels were estimated 20 using a land-use regression model developed for a previous project(37). Noise was calculated 21 as the proportion of street length above a 55 dB(A) threshold(38). A bikeability index was 22 calculated taking into account five factors shown to influence bicycling: bicycle facility 23 availability, bicycle facility quality, street connectivity, topography, and land use(39). 24 Commute distance did not use buffers and it was calculated in km following the street

network of the shortest route from home address to work address. Further details of the
 environmental determinants calculation are given elsewhere(24).

Statistical analyses

A Generalized Additive Model (GAM) was used to test linearity between perceived stress and total physical activity (Total PA), moderate-to-vigorous physical activity (MVPA), vigorous physical activity (VPA), and age(40). As there was no statistical evidence to reject linearity between perceived stress and Total PA (p-value = 0.3816), MVPA (p-value = 0.5025), VPA (p-value = 0.1630), and age (p-value = 0.2282), these variables were included as continuous variables in the model assuming a linear relationship. Multivariate Poisson regression with robust variance models were used to assess the relationship between bicycle commuting and perceived stress. Possible mediation by different levels of PA between bicycle commuting and perceived stress, and any interaction between gender and bicycle commuting were also tested with Poisson regression with robust variance models. All regression models were conducted with a complete case analysis and included individual and environmental potential confounders that showed a p-value < 0.05 in the bivariate analysis as well as those found to be statistically significant within previous literature. The first descriptive statistical analyses were conducted in Stata version SE 12 (StataCorp LP, Texas USA), while Poisson regression with robust variance models were conducted in Stata version SE 14 (StataCorp LP, Texas USA).

RESULTS

The included sample had an equal distribution of genders and the median age (P25-P75) was 36 (29-43) years (Table 1). The majority of participants were non-stressed (had a stress score equal or lower than 3), Spanish, possessing university studies completed or equivalent-level education, living with their family or partner, living with at least 2 employed people and not Page 11 of 34

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1	with children (64.34%). Among those living with children, 8.12% had children younger than
2	3 years of age. The sample had positive self-perception of health (with only $<1\%$ of
3	participants self-perceiving bad or very bad health), healthy weight according to BMI
4	(71.12%), and generally no chronic disease (92.26%). Bicycle commuters were statistically
5	significant more likely to be non-stressed; younger (35 years); men; have higher levels of PA;
6	possess a university or equivalent-level education; live alone and/or with flat mates with 0-1
7	employed people; have no children; and have better self-perception of health, and healthy
8	weight, but more chronic diseases than non-bicycle commuters. The majority of participants
9	considered that they could release stress when riding a bicycle and that they enjoyed their trip
10	more if they used a bicycle. Bicycle commuters had shorter commutes compared to non-
11	bicycle commuters, and we observed a gradient between commute distance and bicycle
12	commuting levels with shorter distances for those who cycled more frequently. This tendency
13	was also followed by bicycle commuting propensity, with decreasing commute distance from
14	unwilling to bicycle to frequent bicyclists (Table S3). Bicycle commuters also had more
15	public bicycle stations around the home and work/study addresses, lower average greenness
16	around the home address, and higher levels of bikeability at home, work/study address, and
17	on the commute route compared to non-bicycle commuters (Table 1). These environmental
18	determinants stayed statistically significant for bicycle commuting propensity, but not
19	between bicycle commuting levels (Table S3).
20	
21	Women, non-Spanish, those living with 0-1 employed people, and those having a chronic

disease were more likely to be stressed (Table 2). Participants who had more public bicycle
stations around their work/study area and higher levels of bikeability in the work/study

- 24 address area and on the commute route were less likely to be stressed. There was no
- 25 statistically significant relationship between commute distance, greenness, NO₂ and noise, and

1 perceived stress. The possible mediation of PA was not further explored as there was no

2 statistically significant relationship between levels of PA (Total PA, MVPA and VPA) and

3 perceived stress [RR: 1.00; 95% CI: (0.99, 1.00)] for the three different classifications of

4 perceived stress (P50, P75, P90) (Table 2, Table S4).

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1 Table 1. Descriptive analyses of perceived stress and determinants of participants and

2 according to bicycle commuting status.

	Total	sample (788)	Bicycle commuting status				
Variables		sumple (100)	Non-bicycle	commuters (390)	Bicycle co	p-value ^s	
	n	%	n	%	n	%	•
Outcome							
Stressed (median) (Yes)	280	35.53	162	41.97	118	30.33	0.001
Individual determinants							
Age (median; P25-P75)	36	29-43	37	30-45	35	29-41	0.025
Total PA – min/week (median; P25-P75)	424.99	269.99-700.00	374.99	209.99-624.99	484.98	329.99-734.99	< 0.00
MVPA – min/week (median; P25-P75)	197.49	72.50-374.99	90.00	0-40	299.99	159.99-464.99	< 0.00
VPA – min/week (median; P25-P75)	72.50	0-180.00	35.00	0-134.99	105.00	0-225.00	< 0.00
Sex (Woman)	410	52.03	234	60.00	176	44.22	<0.00
Country of birth (non-Spanish)	97	12.31	41	10.51	56	14.11	0.12
Working status (Student)	104	13.20	347	87.19	51	12.81	0.74
equivalent-level education)	551	69.92	247	63.33	304	76.38	< 0.00
Living with family/partner	635	80.58	327	83.85	308	77.58	0.02
Employed people in household (2-5)	510	64.72	261	67.27	249	62.88	0.19
MEDEA index							0.35
1st tertile (least deprived)	263	33.38	130	33.33	133	33.42	
2nd tertile	263	33.38	122	31.28	141	35.43	
3rd tertile (most deprived)	262	33.25	138	35.38	124	31.16	
Children in household (Yes)	279	35.41	151	38.82	128	32.24	0.05
Children <3 years in household (Yes)	64	8.12	36	9.25	28	7.07	0.26
Self-perceived health (Very good/Excellent)	323	40.99	140	35.90	183	45.98	0.00
BMI (Overweight/Obese)	212	26.9	124	31.96	88	22.11	0.00
Chronic disease (Yes)	61	7.74	25	6.41	36	9.05	0.16
Stress releasing (Agreement)	658	83.50	302	79.47	356	90.59	<0.0
Bicycle trip enjoyment (Agreement)	629	/9.82	249	65.35	380	96.20	<0.00
Environmental determinants							
	3.85	2.05	4.38	2.25	3.35	1.70	< 0.00
Commute distance, estimated (km) (mean;SD)							
Public bicycle stations (mean;SD)							
Home, count in 400m buffer	4.25	2.54	3.75	2.51	4.75	2.47	< 0.0
Work/study, count in 400m buffer	4.92	3.11	4.50	3.13	5.33	3.04	<0.0
Greenness, NDVI [IOR, (mean:SD)]							
Home average of 400m buffer	0.79	1.07	0.91	1.08	0.68	1.06	< 0.0
Work/study average of 400m buffer	0.62	0.96	0.70	1.07	0.55	0.83	0.08
Commute mute average of 400m burlet	0.97	0.96	1.07	1.06	0.87	0.85	0.06
NO ₂ nph (mean SD)	0.97	0.90	1.07	1.00	0.07	0.05	0.00
Home concentration in 400m buffer	76.20	17.52	75.16	17.12	77.21	17.87	0.05
Werk/study, concentration in 400m build	78.43	22.51	78 56	23.92	78 31	21.10	0.84
work/study, concentration in 400m buller	94.40	16.07	94.24	16.82	94.55	17.12	0.0
Commute route, concentration in RBA	64.40	10.97	04.24	10.82	04.55	17.15	0.90
Noise, >55dB (%) (mean;SD)							
Home, proportion in 400m buffer	78.63	11.40	78.77	10.99	78.50	11.79	0.82
Work/study, proportion in 400m buffer	79.59	14.66	79.09	14.86	80.07	14.46	0.36
Commute route, proportion in RBA	77.40	9.04	77.51	8.58	77.30	9.48	0.92
Bikeability (mean;SD)							
Home, concentration in 400m buffer	6.20	1.41	5.93	1.45	6.46	1.31	< 0.0
Work/study_concentration in 400m huffer	6.56	1.39	6.31	1.54	6.79	1.17	< 0.0
Commute route concentration in DDA	6 70	1.12	6.45	1 20	6.94	0.98	<0.00

PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; BMI, Body Mass Index; NDVI, Normalized Difference Vegetation Index; RBA, Route-By-Area. Data are n and %, unless otherwise noted. There are missing data in: Perceived stress (13; 1.65%), Total PA (5; 0.63%), Country of birth (1; 0.13%), Living with family/partner (1; 0.13%), Employed people in household (4; 0.51), Children in household (2; 0.25%), Children <3years old in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂ (20; 2.54%). *Chi square test, except for Age, Total PA, MVPA, VPA, and all the Environmental determinants (U Mann Whitney test).

Table 2. Bivariate analyses showing the relationships between perceived stress (median) and

determinants of participants.

Variable	Perceived stress				
variable	RR	p-value			
Individual determinants					
Age	1.00	(0.99, 1.01)	0.502		
Total PA - min/week	1.00	(0.99, 1.00)	0.669		
MVPA - min/week	1.00	(0.99, 1.00)	0.114		
VPA - min/week	1.00	(0.99, 1.00)	0.658		
Gender (Woman)	1.55	(1.27, 1.89)	< 0.001		
Country of birth (Spain)	1.34	(1.05, 1.70)	0.017		
Working status (Student)	1.22	(0.95, 1.56)	0.115		
Education level (University studies completed			0.207		
or Others)	0.92	(0.75, 1.12)	0.387		
Living with family/partner	0.91	(0.73, 1.15)	0.439		
Employed people in household (2-5)	0.74	(0.62, 0.90)	0.002		
MEDEA index					
1st tertile (least deprived)	1.00				
2nd tertile	1.08	(0.85, 1.37)	0.537		
3rd tertile (most deprived)	1.18	(0.94, 1.48)	0.162		
Children in household (Yes)	0.90	(0.74, 1.11)	0.330		
Children <3 years in household (Yes)	0.87	(0.60, 1.27)	0.475		
Self-perceived health (Very good/Excellent)	0.87	(0.71, 1.06)	0.157		
BMI (Overweight/Obese)	0.95	(0.77, 1.18)	0.669		
Chronic disease (Yes)	1.38	(1.04, 1.83)	0.024		
Stress releasing (Agreement)	0.87	(0.68, 1.11)	0.273		
Bicycle trip enjoyment (Agreement)	0.91	(0.72, 1.14)	0.425		
Environmental determinants					
Commute distance estimated (km)	1.02	(0.97, 1.06)	0.508		
Public bicycle stations		(
Home, count in 400m buffer	0.99	(0.95, 1.02)	0.503		
Work/study, count in 400m buffer	0.96	(0.93, 0.99)	0.024		
Greenness, NDVI					
Home, average of 400m buffer	0.94	(0.85, 1.05)	0.258		
Work/study, average of 400m buffer	1.06	(0.96, 1.16)	0.241		
Commute route, average of RBA	0.99	(0.89, 1.09)	0.838		
NO ₂ ppb					
Home, concentration in 400m buffer	1.00	(0.99, 1.01)	0.827		
Work/study, concentration in 400m buffer	1.00	(0.99, 1.00)	0.100		
Commute route, concentration in RBA	1.00	(0.99, 1.00)	0.518		
Noise, >55dB					
Home, proportion in 400m buffer	1.00	(0.98, 1.00)	0.363		
Work/study, proportion in 400m buffer	1.01	(0.99, 1.01)	0.125		
Commute route, proportion in RBA	1.00	(0.98, 1.01)	0.405		
Bikeability					
Home, concentration in 400m buffer	1.00	(0.94, 1.07)	0.931		
Work/study, concentration in 400m buffer	0.92	(0.86, 0.98)	0.009		
Commute route concentration in RBA	0.91	(0.84, 0.98)	0.018		

PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; BMI, Body Mass Index; NDVI, Normalized Difference Vegetation Index; RBA, Route-By-Area. Complete case analysis excluding missing data of the variables of final models (Table 3; n=771). The variables that still present missing data and are not included in the final models are: Total PA (5; 0.63%), People living with in household (1; 0.13%), Children in household (2; 0.25%), Children - Syears old in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂ (20; 2.54%).

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1	Multivariate Poisson regression with robust variance analyses showed a statistically
2	significant inverse relationship between bicycle commuting and perceived stress. Bicycle
3	commuters had a lower risk of being stressed compared to non-bicycle commuters [RR
4	(95%CI) = 0.73 (0.60, 0.89)]. This relationship remained after adjusting for confounders
5	(individual and environmental) and when using P75 and P90 perceived stress cut-offs (Table
6	3, Table S5). There was a statistically significant inverse relationship between medium and
7	high levels of bicycle commuting and perceived stress using non-bicycle commuters as a
8	reference group [RR (95%CI) = 0.46 (0.28, 0.78); RR (95%CI) = 0.63 (0.49, 0.81)] and also
9	when using low levels of bicycle commuting [RR $(95\%$ CI) = 0.42 $(0.24, 0.73)$; RR $(95\%$ CI) =
10	0.57 (0.42, 0.77)] as a reference group. This statistically significant relationship remained in
11	the majority of sensitivity analyses Regarding bicycle commuting propensity, there was a
12	statistically significant inverse relationship between frequent bicycle commuters and
13	perceived stress, using unwilling non-bicycle commuters [RR (95%CI) = 0.53 (0.41, 0.67)]
14	and infrequent bicycle commuters [RR $(95\%$ CI) = 0.54 $(0.40, 0.72)$] as respective reference
15	groups. The statistically significant relationship remained after adjusting for individual and
16	environmental confounders and when using perceived stress P75 and P90 as cut-offs . Also,
17	there was a statistically significant inverse relationship between willing non-bicycle
18	commuters and perceived stress, using unwilling non-bicycle commuters [RR $(95\%CI) = 0.72$
19	(0.56, 0.94)] as a reference group in the bicycle commuting propensity variable and also
20	looking only in the non-bicycle commuting group. This relationship remained after adjusting
21	for individual and environmental confounders, but not when using perceived stress at the P75
22	and P90 cut-offs.
23	
24	In the fully adjusted models, we found no statistically significant interactions between gender
25	and bicycle commuters (p-value= 0.165) between gender and bicycle commuting levels (p-

- 1 value=0.226, p-value=0.266, p-value=0.431), or between gender and bicycle commuting
- 2 propensity (p-value=0.982, p-value=0.197, p-value=0.277) (results not shown).

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Table 3. Multivariate models showing the relationships between bicycle commuting and perceived stress (median) of participants.

	Perceived stress											
Variable	RR Unadjusted (95% CI)		p-value	RI	RR Adjusted ^a (95% CI)		RR Adjusted ^b (95% CI)		p-value	RR Adjusted ^c (95% CI)		p-value
All sample (771)												
Bicycle commuting status												
Non-bicycle commuters	1.00			1.00			1.00			1.00		
Bicycle commuters	0.73	(0.60, 0.89)	0.001	0.75	(0.62, 0.91)	0.003	0.77	(0.63, 0.94)	0.009	0.80	(0.66, 0.99)	0.036
Bicycle commuting levels												
Non-bicycle commuters (0 days)	1.00			1.00			1.00			1.00		
Low bicycle commuting (1-3 days)	1.10	(0.87, 1.39)	0.436	1.11	(0.88, 1.40)	0.369	1.13	(0.89, 1.44)	0.297	1.17	(0.92, 1.48)	0.205
Medium bicycle commuting (4 days)	0.46	(0.28, 0.78)	0.004	0.45	(0.27, 0.74)	0.002	0.45	(0.27, 0.75)	0.002	0.48	(0.29, 0.80)	0.005
High bicycle commuting (>=5 days)	0.63	(0.49, 0.81)	< 0.001	0.66	(0.51, 0.85)	0.001	0.68	(0.52, 0.88)	0.003	0.71	(0.54, 0.92)	0.010
Bicycle commuting propensity												
Unwilling Non-bicycle commuters	1.00			1.00			1.00			1.00		
Willing Non-bicycle commuters	0.72	(0.56, 0.94)	0.014	0.75	(0.58, 0.97)	0.029	0.74	(0.57, 0.96)	0.022	0.75	(0.58, 0.97)	0.031
Infrequent Bicycle commuters	0.98	(0.76, 1.25)	0.847	1.00	(0.78, 1.27)	0.980	1.01	(0.79, 1.30)	0.949	1.04	(0.81, 1.34)	0.739
Frequent Bicycle commuters	0.53	(0.41, 0.67)	< 0.001	0.55	(0.43, 0.70)	< 0.001	0.56	(0.43, 0.72)	< 0.001	0.58	(0.45, 0.76)	< 0.001
Bicycle commuters sample (387)												
Bicycle commuting levels												
Low bicycle commuting (1-3 days)	1.00			1.00			1.00			1.00		
Medium bicycle commuting (4 days)	0.42	(0.14, 0.59)	0.002	0.39	(0.23, 0.67)	0.001	0.39	(0.23, 0.65)	< 0.001	0.38	(0.23, 0.65)	< 0.001
High bicycle commuting (>=5 days)	0.57	(0.26, 0.68)	< 0.001	0.59	(0.44, 0.80)	0.001	0.59	(0.44, 0.80)	0.001	0.59	(0.44, 0.80)	0.001
Bicycle commuters propensity												
Infrequent (1-3 days)	1.00			1.00			1.00			1.00		
Frequent (>=4 days)	0.54	(0.24, 0.62)	< 0.001	0.55	(0.41, 0.73)	< 0.001	0.54	(0.41, 0.72)	< 0.001	0.54	(0.41, 0.72)	< 0.001
Non-bicycle commuters sample (384)												
Non-bicycle commuters												
Unwilling	1.00			1.00			1.00			1.00		
Willing	0.72	(0.38, 0.89)	0.015	0.73	(0.57, 0.95)	0.020	0.72	(0.56, 0.93)	0.013	0.74	(0.57, 0.95)	0.020

³ Adjusted by Gender, Country of birth, Employed people in household, Chronic disease. ^bAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). ^cAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). ^cAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). ^cAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). ^cAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, MVPA, Public bicycle stations at work/study, Bikeability at commute route.

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DISCUSSION

2 Summary of results

We evaluated relationships between bicycle commuting and perceived stress while adjusting for several confounders in a representative sample of adults in Barcelona, Spain. We found statistically significant inverse relationships between several measures of bicycle commuting and perceived stress. Bicycle commuters who bicycled four or more days per week had lower risk of being stressed compared to those who cycled less or did not bicycle on their commute. This relationship remained statistically significant in all sensitivity analyses and after controlling for individual and environmental confounders.

11 Comparison with previous studies

To our knowledge, this study is the first to assess whether a relationship exists between bicycle commuting and perceived stress. A few studies have focused on the relationship between active commuting and mental health(6,7,29), but the relationship is still unclear. One study found a positive association between active commuting and well-being(6), and another with better mental health in men(29). Moreover, Humphreys(7) found a positive relationship between time spent actively commuting and levels of physical well-being, but not with mental well-being. The relationship between physical activity and mental health has been studied more. It has been suggested that physical activity could reduce stress and anxiety on a daily basis while improving self-perception and mood(41-43), and it has been associated with lower depressive symptomatology and greater emotional well-being(44). These findings suggest that the physical activity gained during bicycle commuting(31) may act as a mediator in the relationship between bicycle commuting and perceived stress. Our results are consistent with the general idea that active commuting is associated with better mental health, but in our

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1	case physical activity did not act as a mediator in this relationship. Our sample was
2	composed of young, healthy, and active participants with low levels of perceived stress,
3	which might have led to an underestimation of the relationship between PA and perceived
4	stress.
5	
6	Qualitative research suggested that choice of travel mode may affect well-being(19). The
7	quantity of public bicycle (Bicing) stations and the amount of greenness has been related to
8	bicycle commuting propensity(24), which could imply that commuting by bicycle provides
9	people with more opportunities to "enjoy" or "experience" greenness than commuting on
10	public transport or a car. At the same time, the availability of green space close to one's home
11	has been shown to be related to better self-perceived general health and better mental
12	health(25,26,45). Therefore, it seems that perceptual and environmental factors related to
13	bicycle commuting could affect perceived stress, in the way that more pleasant an
14	environment to bicycle commute is, better perceived stress results we will get. This general
15	idea is consistent with our results which show an inverse relationship between perceived
16	stress and bicycle-friendly environments (public bicycle stations and bikeability levels) in
17	work/study address area and the commute route. Importantly, the relationship between
18	bicycling and stress was unchanged after controlling for the environmental confounders. Our
19	results also showed that general attitude might have a role in this relationship, as we have seen
20	that those willing non-bicycle commuters, compared to unwilling non-bicycle commuters,
21	were less stressed. But this remained quite unclear as the relationship becomes statistically no
22	significant in the sensitivity analyses.

2 Limitations and strengths

Our study had some limitations. Firstly, our study used a cross-sectional design, which is not well-suited to assess the direction of causation, and we cannot exclude reverse causality or residual confounding. It has been suggested that stressed people can engage in unhealthy behaviours, such as poor dietary practices or a lack of physical activity (46). This reasoning could be applied to a behaviour like bicycle commuting, where those individuals who are more stressed would bicycle less. Secondly, our measurement method may be prone to information bias. With the questionnaire data we could have random misclassification error of bicycle commuting and PA because of the data being self-reported. Therefore, the risk estimate and also the potential mediation by PA could be under-estimated(47). The TAPAS Travel Survey only measured levels of PA without differentiating between types of PA (work, travel, recreational). Furthermore, the modification of the 5-point PSS-4 Likert scale into a 4-point Likert scale could incorrectly-estimate the perceived stress.

This study had several strengths, too. The study had high internal validity, with a good representation of bicycle commuters. Related to participants' characteristics, the TAPAS Travel Survey sample is representative of Barcelona's population from the socio-demographic point of view. It was compared with data from the Catalan government's Barcelona Active Population Survey (Statistics and information service, Catalan government 2011) and no statistically significant differences between participants' deprivation index and home and work population density in both surveys were found(24,31). Finally, our study in a southern European city has added evidence in a different context than the current literature on these issues.

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1 Future research

Our findings underscored the need for future research. There is a need to obtain a clear understanding of the relationship between the bicycle commuting and perceived stress in longitudinal studies. The role of PA in this relationship seems unclear, and it is likely that other factors could affect the relationship between these two variables, especially those related to environmental determinants and personal attitudes. Further work related to determinants and mediators of bicycle commuting and perceived stress is needed.

8 CONCLUSIONS

We found that healthy, adult bicycle commuters had lower risk of being stressed than commuters of other transport modes. Also, bicycle commuters who bicycled four or more days per week had lower risk of being stressed than those who bicycled less than that. Environmental determinants such as the number of public bicycle stations and bikeability, and also personal attitudes seem to have an influence on this relationship. Further research is needed in order to disentangle the relationship between bicycle commuting and perceived stress, and its determinants (individual and environmental) and potential mediators. Our findings suggest that decision-makers may promote bicycle commuting as a daily routine, to reduce stress levels and improve public health and well-being.

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COMPETING INTERESTS

13 No conflicts of interest were reported by the authors of this paper.

14 AUTHOR'S CONTRIBUTION

15 MJN and AdN obtained the funding and designed the study. IAP conducted the analyses and

16 drafted this version of the paper and received input from all the authors. All authors read and

17 commented on the paper and agreed with the final version.

18 DATA SHARING

19 Extra data is available by emailing the corresponding author (Ione Avila-Palencia:

20 ione.avila@isglobal.org).

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SUPPLEMENTARY MATERIAL

Table S1. PSS4 questions used in TAPAS Travel Survey

Q218. In the last month, how often have you felt that you were unable to control important things in your life?

0	Never
1	Almost never
2	Nearly always
3	Always
997	Don't Know
998	Refuse to Answer

- *Q219.* In the last month, how often have you felt confident about your ability to handle your personal problems?
 - 0 Never
 1 Almost never
 2 Nearly always
 3 Always
 997 Don't Know
 998 Refuse to Answer

Q220. In the last month, how often have you felt that things were going your way?

- Never
 Almost never
 Nearly always
 Always
 Don't Know
 Refuse to Answer
- *Q221.* In the last month, how often have you felt that difficulties were piling up so high that you could not overcome them?
 - Never
 - 1 Almost never
 - 2 Nearly always
 - 3 Always
 - 997 Don't Know
 - 998 Refuse to Answer

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PSS-4 score	n	%	Cumulative %	
0	90	11.61	11.61	
1	125	16.13	27.74	
2	129	16.65	44.39	
3	151	19.48	63.87	
4	144	18.58	82.45	
5	38	4.90	87.35	
6	33	4.26	91.61	
7	12	1.55	93.16	
8	28	3.61	96.77	
9	5	0.65	97.42	
10	11	1.42	98.84	
11	3	0.39	99.23	
12	4	0.52	99.74	
13	1	0.13	99.87	
14	1	0.13	100.00	
Total	775	100.00		

 Table S2. PSS4 score distribution in TAPAS Travel Survey sample

Table S3. Description of the individual and environmental determinants in TAPAS

sample for Bicycle commuting levels and Bicycle commuting propensity.

			Bicy	cle commutin	g levels						Bicycle c	ommuting	propensity			_
Variables		Low (109)	Mee	lium (5)	E C	ligh 224)		U	nwilling (230)	v	(illing (160)	Infre	quent (109)	Fi	requent (289)	
	n	%	n	%	n	%	p-value	n	%	n	%	n	%	n	%	I
Outcome																
Stressed (median)(Yes)	49	45.37	12	19.05	57	26.15	<0.001	107	46.93	55	34.81	49	45.37	69	24.56	
Individual determinants																
Age (median; P25-P75)	36	28-42	36	28-45	35	29-41	0.777	37	30-46	36	29.5-45	36	28-42	35	29-41	
Total PA - min/week (median; P25-P75)	494.99	299.99- 734.994	454.99	359.99- 689.99	484.99	339.99- 779.99	0.567	364.99	209.99-600.00	404.99	209.99-629.99	494.99	299.99-734.99	480.00	339.99-744.99	
MVPA - min/week (median; P25-P75)	240.00	134.99-480	294.99	189.99- 390.00	300.00	177.49- 479.99	0.092	90.00	0-244.99	90.00	0-240.00	240.00	134.99-480.00	300.00	179.99-450.00	
VPA - min/week (median; P25-P75)	120.00	0-224.99	90.00	0-199.99	102.50	0-240.00	0.386	45.00	0-150.00	0	0-127.50	120.00	0-224.99	90.00	225.00	
Gender (Woman)	49	44.95	33	50.77	94	41.96	0.446	151	65.65	83	51.88	49	44.95	127	43.94	
Country of birth (non-Spanish)	19	17.59	7	10.77	30	13.39	0.412	16	6.96	25	15.63	19	17.59	37	12.80	
Working status (Student)	17	15.60	10	15.38	24	10.71	0.364	24	10.43	29	18.13	17	15.60	34	11.76	
Education level (University studies completed or equivalent-level education)	81	74.31	50	76.92	173	77.23	0.836	161	70.00	86	53.75	81	74.31	223	77.16	
Living with family/partner	88	80.73	48	75.00	172	76.79	0.622	192	83.48	135	84.38	88	80.73	220	76.39	
Employed people in household (2-5)	69	63.30	35	55.56	145	64.73	0.410	152	66.09	109	68.99	69	63.30	180	62.72	
MEDEA index							0.627									
1st tertile (least deprived)	35	32.11	23	35.38	75	33.48		81	35.22	49	30.63	35	32.11	98	33.91	
2nd tertile	38	34.86	27	41.54	76	33.93		66	28.70	56	35.00	38	34.86	103	35.64	
3rd tertile (most deprived)	36	33.03	15	23.08	73	32.59		83	36.09	55	34.38	36	33.03	88	30.45	
Children in household (Yes)	31	28.44	18	28.13	79	35.27	0.340	94	40.87	57	35.85	31	28.44	97	33.68	
Children <3 years in household (Yes)	3	2.75	5	7.94	20	8.93	0.114	20	8.73	16	10.00	3	2.75	25	8.71	
Self-perceived health (Very good/Excellent)	43	39.45	27	41.54	113	50.45	0.123	90	39.13	50	31.25	43	39.45	140	48.44	
BMI (Overweight/Obese)	25	22.94	14	21.54	49	21.88	0.969	73	31.88	51	32.08	25	22.94	63	21.8	
Chronic disease (Yes)	11	10.09	8	12.31	17	7.59	0.458	18	7.83	7	4.38	11	10.09	25	8.65	
Stress releasing (Agreement)	95	87.16	62	98.41	199	90.05	0.047	163	72.44	139	89.68	95	87.16	261	91.90	
Bicycle trip enjoyment (Agreement)	103	94.50	65	100.00	212	95.93	0.175	116	51.79	133	84.71	103	94.50	277	96.85	
Environmental determinants																
Commute distance, estimated (km) (mean:SD)	3.73	1.97	3.43	1.70	3.13	1.52	0.044	4.42	2.35	4.32	2.11	3.73	1.97	3.20	1.56	
Public bicycle stations (mean;SD)																
Home, count in 400m buffer	4.61	2.61	4.97	2.63	4.75	2.35	0.492	3.77	2.53	4.32	2.11	3.73	1.97	3.20	1.56	
Work/study, count in 400m buffer	4.89	2.96	5.89	3.11	5.39	3.05	0.124	4.36	2.96	4.71	3.35	4.89	2.96	5.50	3.06	
Greenness, NDVI (mean;SD)																
Home, average of 400m buffer	0.83	1.30	0.75	0.98	0.59	0.94	0.635	0.90	1.03	0.91	1.16	0.83	1.30	0.62	0.95	
Work/study, average of 400m buffer	0.60	0.82	0.37	0.57	0.58	0.90	0.136	0.68	1.11	0.74	1.01	0.60	0.82	0.53	0.84	
Commute route, average of RBA	0.95	0.94	0.76	0.83	0.87	0.81	0.322	1.10	1.11	1.02	0.98	0.95	0.94	0.84	0.81	
NO2, ppb (mean;SD)																
Home, concentration in 400m buffer	74.76	18.70	77.24	16.14	78.40	17.90	0.186	75.59	17.08	74.51	17.20	74.76	18.70	78.14	17.49	
Work/study, concentration in 400m buffer	76.49	21.63	83.02	18.82	77.81	21.37	0.091	78.50	23.84	78.64	24.11	76.49	21.63	79.00	20.90	
Commute route, concentration in RBA	82.86	16.10	87.47	15.22	84.51	18.08	0.127	85.22	17.34	82.76	15.95	82.86	16.10	85.19	17.48	
Noise, >55dB (mean;SD)																
Home, proportion in 400m buffer	78.73	13.39	77.65	9.77	78.63	11.54	0.554	79.03	11.00	78.39	11.01	78.73	13.39	78.41	11.16	
Work/study, proportion in 400m buffer	81.64	13.60	80.04	13.80	79.32	15.04	0.468	78.46	15.47	80.00	13.94	81.64	13.60	79.48	14.75	
Commute route, proportion in RBA	78.62	9.13	75.40	9.26	77.21	9.64	0.057	77.12	8.43	78.08	8.78	78.62	9.13	76.80	9.57	
Bikeability (mean;SD)																
Home, concentration in 400m buffer	6.29	1.44	6.49	1.23	6.54	1.27	0.330	5.88	1.45	6.00	1.45	6.29	1.44	6.53	1.26	
Work/study, concentration in 400m buffer	6.82	1.28	6.88	0.98	6.75	1.17	0.638	6.21	1.58	6.46	1.47	6.82	1.28	6.78	1.13	
Commute route, concentration in RBA	6.77	1.10	7.02	0.93	6.99	0.93	0.236	6.36	1.22	6.58	1.16	6.77	1.10	7.00	0.93	

PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; MBI, Body Mass Index. Data are n and %, unless otherwise noted. There are missing data in: Perceived stress (13: 1.65%), Country of birth (1: 0.13%), Living with family/partner (1; 0.13%), Employed people in household (4: 0.51), Children in household (2: 0.25%), Children <3years old in household (3: 0.38), BMI (2: 0.25%); Stress releasing (15: 1.90%), Bicycle trip enjoyment (12: 1.52%), Commute distance (20: 2.54%), Greenness (20; 2.54%), NO₂ (20; 2.54%). "Chi square test, instead of Age, Total PA, MVPA, VPA, and all the Environmental determinants (U Mann Whitney test).

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Table S4. Sensitivity analyses exploring the relationships between perceived stress

(P75, P90) and all covariates.

Variable		Perceived stress	(P75)	Perceived stress (P90)				
, ar haby	R	R (95% CI)	p-value	RI	R (95% CI)	p-value		
Individual determinants								
	1.00	(0.99, 1.02)	0.793	1.00	(0.97, 1.02)	0.662		
Total PA - min/week	1.00	(0.99, 1.00)	0.113	1.00	(0.99, 1.00)	0.802		
MVPA min/week	1.00	(0.99, 1.00)	0.197	1.00	(0.99, 1.00)	0.701		
	1.00	(0.99, 1.00)	0.382	1.00	(0.99, 1.00)	0 743		
Gender (Woman)	1 41	(1.03, 1.93)	0.032	1.69	(1.04, 2.76)	0.035		
Country of birth (non-Spanish)	1.16	(0.75, 1.78)	0.515	1.14	(0.58, 2.24)	0.695		
Working status (Student)	1.46	(0.99, 2.14)	0.051	1.04	(0.53, 2.04)	0.904		
Education level (University studies completed or equivalent-level education)	0.78	(0.57, 1.07)	0.119	0.80	(0.49, 1.30)	0.369		
Living with family/partner	1.00	(0.68, 1.47)	0.987	0.94	(0.53, 1.68)	0.841		
Employed people in household (2-5) MEDEA index	0.67	(0.50, 0.91)	0.011	0.75	(0.47, 1.20)	0.231		
1 st tertile (least deprived)	1.00			1.00				
2nd tertile	1.42	(0.96, 2.11)	0.081	1.85	(0.99, 3.46)	0.054		
3rd tertile (most deprived)	1.45	(0.97, 2.14)	0.067	1.77	(0.94, 3.33)	0.076		
Children in household (Yes)	1.05	(0.76, 1.44)	0.778	0.92	(0.56, 1.51)	0.743		
Children <3 years in household (Yes)	0.61	(0.30, 1.25)	0.180	0.54	(0.17, 1.68)	0.289		
Self-perceived health (Very good/Excellent)	0.65	(0.47, 0.91)	0.011	0.88	(0.55, 1.42)	0.604		
BMI (Overweight/Obese)	1.08	(0.77, 1.51)	0.664	1.03	(0.61, 1.73)	0.922		
Chronic disease (Yes)	1.58	(1.01, 2.48)	0.047	1.66	(0.83, 3.32)	0.150		
Stress releasing (Agreement)	0.85	(0.57, 1.27)	0.423	0.94	(0.49, 1.79)	0.850		
Bicycle trip enjoyment (Agreement)	0.74	(0.52, 1.04)	0.085	0.79	(0.46, 1.37)	0.409		
Environmental determinants								
Commute distance, estimated (km)	1.07	(0.99, 1.14)	0.053	1.03	(0.92, 1.15)	0.620		
Public bicycle stations								
Home, count in 400m buffer	0.99	(0.93, 1.06)	0.770	0.94	(0.84, 1.04)	0.253		
Work/study, count in 400m buffer	0.96	(0.91, 1.01)	0.103	0.96	(0.89, 1.03)	0.242		
Greenness, NDVI								
Home, average of 400m buffer	0.95	(0.79, 1.14)	0.557	1.04	(0.81, 1.33)	0.768		
Work/study, average of 400m buffer	1.09	(0.94, 1.27)	0.262	0.99	(0.74, 1.32)	0.936		
Commute route, average of RBA	1.04	(0.88, 1.22)	0.655	1.18	(0.95, 1.47)	0.138		
NO ₂ , ppb								
Home, concentration in 400m buffer	1.00	(0.99, 1.00)	0.390	1.00	(0.98, 1.01)	0.728		
Work/study, concentration in 400m buffer	0.99	(0.99, 1.00)	0.042	0.99	(0.98, 1.00)	0.076		
Commute route, concentration in RBA	1.00	(0.99, 1.01)	0.474	0.99	(0.97, 1.00)	0.138		
Noise, >55dB								
Home, proportion in 400m buffer	1.01	(0.99, 1.02)	0.483	1.00	(0.98, 1.03)	0.845		
Work/study, proportion in 400m buffer	1.00	(0.99, 1.01)	0.549	1.00	(0.98, 1.02)	0.835		
Commute route, proportion in RBA	1.00	(0.98, 1.01)	0.854	1.01	(0.98, 1.04)	0.444		
Bikeability								
Home, concentration in 400m buffer	0.97	(0.87, 1.08)	0.532	0.92	(0.78, 1.09)	0.356		
Work/study, concentration in 400m buffer	0.92	(0.82, 1.02)	0.108	0.89	(0.75, 1.07)	0.216		
Commute route concentration in RBA	0.88	(0.77, 1.00)	0.055	0.81	(0.66, 0.99)	0.042		

PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; BMI, Body Mass Index. There are missing data in: Perceived stress (13; 1.65%), Country of birth (1; 0.13%), People living with in household (1; 0.13%), Employed people in household (4; 0.51), Children in household (2; 0.25%), Children <a href="https://www.aresolut.com/aresolut.co

Table S5. Sensitivity analyses exploring the relationships between bicycle commuting (Bicycle commuting status, Bicycle commuting

levels, Bicycle commuting propensity) and perceived stress (P75, P90).

7																									
8	Variable	pp 1	Inadiusted		pp	Adjusteda	Perceived	stress (P75	5) Adjusted ^b		pp	Adjusted ^c		pp	Unadjusted		ръ	A dineted ^a	Perceived str	ess (P90)	Adjusted ^b		pp	Adjusted ^c	
a		(9	5% CI)	p-value	кк (9	95% CI)	p-value	(9	95% CI)	p-value	(9	5% CI)	p-value	кк (95% CI)	p-value	(9	5% CI)	p-value	(9	5% CI)	p-value	(9	5% CI)	p-value
9	All sample (771)																								
10	Bicycle commuting status																								
11	Non-bicycle commuters	1.00	(0.10.0.70)	0.001	1.00	(0.40.0.70)	0.001	1.00	0.44.0.05	0.004	1.00	(0.46.0.00)	0.011	1.00	(0.22.0.00)	0.014	1.00	(0.04, 0.02)	0.005	1.00	(0.01, 0.00)	0.014	1.00	(0.22, 0.05)	0.022
12	Bicycle commuters	0.58	(0.42, 0.79)	0.001	0.58	(0.42, 0.79)	0.001	0.61	(0.44, 0.85)	0.004	0.64	(0.46, 0.90)	0.011	0.54	(0.33, 0.89)	0.014	0.56	(0.34, 0.93)	0.025	0.52	(0.31, 0.88)	0.014	0.56	(0.33, 0.95)	0.032
12	Bicycle commuting levels	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
13	Low bicycle commuting (1-3 days)	1.00	(0.71, 1.54)	0.832	1.00	(0.70, 1.53)	0.868	1.08	(0.73, 1.59)	0.708	1.10	(0.74, 1.64)	0.626	1.00	(0.68, 2.11)	0.535	1.22	(0.68, 2.21)	0.505	1.14	(0.63, 2.07)	0.662	1.18	(0.65, 2.14)	0.573
14	Medium bicycle commuting (1-5 days)	0.22	(0.07, 0.66)	0.007	0.20	(0.07, 0.62)	0.005	0.21	(0.07, 0.65)	0.007	0.22	(0.07, 0.68)	0.009	0.15	(0.02, 1.05)	0.056	0.14	(0.02, 1.00)	0.050	0.14	(0.02, 0.95)	0.044	0.15	(0.02, 1.04)	0.054
15	High bicycle commuting (>=5 days)	0.45	(0.29, 0.70)	< 0.001	0.46	(0.30, 0.72)	0.001	0.50	(0.32, 0.78)	0.003	0.52	(0.33, 0.82)	0.005	0.34	(0.16, 0.70)	0.004	0.36	(0.17, 0.75)	0.005	0.33	(0.15, 0.69)	0.004	0.35	(0.17, 0.73)	0.005
16	Bicycle commuting propensity																								
10	Unwilling Non-bicycle commuters	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
17	Willing Non-bicycle commuters	0.71	(0.47, 1.06)	0.090	0.74	(0.49, 1.10)	0.135	0.71	(0.48, 1.06)	0.095	0.72	(0.48, 1.08)	0.116	0.66	(0.35, 1.22)	0.183	0.70	(0.38, 1.30)	0.255	0.70	(0.37, 1.30)	0.253	0.71	(0.38, 1.35)	0.298
18	Infrequent Bicycle commuters	0.92	(0.61, 1.38)	0.684	0.92	(0.61, 1.39)	0.695	0.94	(0.63, 1.43)	0.788	0.97	(0.64, 1.48)	0.890	1.03	(0.57, 1.87)	0.926	1.07	(0.57, 2.01)	0.831	1.00	(0.53, 1.88)	0.991	1.04	(0.54, 1.98)	0.915
10	Frequent Bicycle commuters	0.35	(0.23, 0.54)	<0.001	0.36	(0.23, 0.55)	<0.001	0.58	(0.24, 0.59)	<0.001	0.40	(0.25, 0.62)	<0.001	0.25	(0.12, 0.52)	<0.001	0.27	(0.13, 0.56)	<0.001	0.25	(0.12, 0.52)	<0.001	0.27	(0.13, 0.56)	<0.001
19	Bicycle commuters sample (387)																								
20	Low bicycle commuting (1-3 days)	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
21	Medium bicycle commuting (4 days)	0.21	(0.06, 0.66)	0.008	0.19	(0.06, 0.61)	0.005	0.19	(0.06, 0.60)	0.005	0.19	(0.06, 0.60)	0.004	0.12	(0.02, 0.92)	0.041	0.11	(0.02, 0.83)	0.032	0.11	(0.02, 0.80)	0.028	0.11	(0.02, 0.76)	0.026
22	High bicycle commuting (>=5 days)	0.43	(0.26, 0.73)	0.002	0.44	(0.26, 0.75)	0.002	0.44	(0.26, 0.75)	0.002	0.44	(0.26, 0.73)	0.002	0.28	(0.12, 0.65)	0.003	0.28	(0.12, 0.65)	0.003	0.27	(0.12, 0.64)	0.003	0.27	(0.12, 0.60)	0.001
22	Bicycle commuters propensity																								
23	Infrequent (1-3 days)	1.00	(0.22, 0.64)	-0.001	1.00	(0.00, 0.(0)	-0.001	1.00	(0.22, 0.(2))	-0.001	1.00	(0.02, 0.02)	10.001	1.00	(0.11, 0.55)	0.001	1.00	(0.11, 0.55)	0.001	1.00	(0.10, 0.54)	0.001	1.00	(0.11.0.51)	-0.001
24	Frequent (>=4 days)	0.38	(0.25, 0.64)	<0.001	0.58	(0.23, 0.63)	<0.001	0.58	(0.23, 0.63)	<0.001	0.58	(0.23, 0.62)	<0.001	0.25	(0.11, 0.55)	0.001	0.24	(0.11, 0.55)	0.001	0.24	(0.10, 0.54)	0.001	0.23	(0.11, 0.51)	<0.001
25	Exposure Non-bicycle commuters sample	(384)																							
26	Unwilling	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
20	Willing	0.71	(0.47, 1.06)	0.090	0.72	(0.48, 1.07)	0.106	0.67	(0.45, 1.00)	0.051	0.69	(0.46, 1.03)	0.068	0.66	(0.35, 1.22)	0.183	0.68	(0.36, 1.26)	0.222	0.68	(0.36, 1.26)	0.221	0.71	(0.37, 1.36)	0.300
27	^a Adjusted by Geno	der, Cour	ntry of birth, E	mployed pe	ople in h	ousehold, Chr	onic diseas	e. ^b Adjus	ted by Age, Ge	ender, Count	ry of birt	h, Employed	people in hous	sehold, Cl	hronic disease,	Self-perceiv	ved healt	h, Moderate-to	o-Vigorous	Physical	Activity (MV	PA). °Adj	usted by		
28	Age, Gender, Cou Barcelona, Spain	ntry of b	irth, Employed	people in l	househol	d, Chronic dise	ease, Self-p	erceived	health, MVPA	, Public bicy	cle statio	ons at work/st	udy, Bikeabili	ty at worl	k/study, Bikeat	oility at com	mute rou	ite. Data were	collected fr	om June	2011 through	to May 20)12 in		
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STROBE Statement-checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Reported in page
Title and abstract	1	(<i>a</i>) Indicate the study's design with a commonly used term in the title or the abstract	Page 2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2
Introduction			
Background/rati onale	2	Explain the scientific background and rationale for the investigation being reported	Pages 4, 5
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5
Methods			
Study design	4	Present key elements of study design early in the paper	Page 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Pages 6, 7
Participants	6	 (a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants 	Pages 6, 7
		(b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed Case-control study—For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Pages 7, 8, 9, 10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Pages 7, 8, 9, 10
Bias	9	Describe any efforts to address potential sources of bias	Pages 6, 7
Study size	10	Explain how the study size was arrived at	Pages 6, 7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Pages 7, 8, 9, 10
Statistical methods	12	(<i>a</i>) Describe all statistical methods, including those used to control for confounding	Page 10
		(b) Describe any methods used to examine subgroups and interactions	Page 10
		(c) Explain how missing data were addressed	Page 10
		(d) Cohort study—If applicable, explain how loss to follow-up was addressed Case-control study—If applicable, explain how matching of cases and controls was addressed Cross-sectional study—If applicable, describe analytical methods taking account of campling strategy	Page 10
Continued on next page	e	(<u>e</u>) Describe any sensitivity analyses	Pages 7, 8, 10

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Results			Reported in page
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 6
		(b) Give reasons for non-participation at each stage	Page 6
		(c) Consider use of a flow diagram	In previous papers
Descriptive	14*	(a) Give characteristics of study participants (eg demographic, clinical,	Pages 10, 11,
data		social) and information on exposures and potential confounders	12, 13, 14
		(b) Indicate number of participants with missing data for each variable of interest	Pages 6, 13, 14
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	-
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	-
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	-
		Cross-sectional study—Report numbers of outcome events or summary	Pages 10, 11,
		measures	12, 13, 14
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted	Pages 15, 16,
		estimates and their precision (eg, 95% confidence interval). Make clear	17
		which confounders were adjusted for and why they were included	
		(b) Report category boundaries when continuous variables were categorized	Pages 7, 8
		(<i>c</i>) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Pages 3, 4, 5 of Supplementar
			material
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 20
Interpretation	20	Give a cautious overall interpretation of results considering objectives,	Pages 18, 19,
		limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	20, 21
Generalisability	21	Discuss the generalisability (external validity) of the study results	Pages 20
Other informatio	on		
Funding	22	Give the source of funding and the role of the funders for the present study	Page 22
		and if applicable for the original study on which the present article is based	

unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The relationship between bicycle commuting and perceived stress: a cross-sectional study

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Page 1 of 34		BMJ Open
1 2		
- 3 4 5	1	THE RELATIONSHIP BETWEEN BICYCLE COMMUTING
6 7	2	AND PERCEIVED STRESS: A CROSS-SECTIONAL STUDY
8 9	3	Ione Avila-Palencia, MPH ^{1, 2, 3} ; Audrey de Nazelle, PhD ⁴ ; Tom Cole-Hunter, PhD ⁵ ; David
10 11	4	Donaire-Gonzalez, PhD ^{1,3,6} ; Michael Jerrett, PhD ⁷ ; Daniel A. Rodriguez, PhD ⁸ ; Mark J
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51 52	23	Keywords : Environmental epidemiology, Physical activity, Stress, Urbanisation, Self-rated
53 54	24	health
55 56	25	Word count of main text: 3562
57 58 59		
60		For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml

ABSTRACT

Introduction: Active commuting –walking and bicycling for travel to and/or from work or educational addresses– may facilitate daily, routine physical activity. Several studies have investigated the relationship between active commuting and commuting stress, but there are no studies examining the relationship between bicycle commuting and perceived stress, or studies that account for environmental determinants of bicycling commuting and stress. The current study evaluated the relationship between bicycle use for commuting among working or studying adults in a dense urban setting and perceived stress.

9 Methods: A cross-sectional study was performed with 788 adults who regularly travelled to

10 work or study locations in Barcelona, Spain, excluding those who only commuted on foot.

11 Participants responded to a comprehensive telephone survey concerning their travel behaviour

12 from June 2011 through to May 2012. Participants were categorised as either bicycle

13 commuters or non-bicycle commuters, and based on the Perceived Stress Scale (PSS-4), as

14 stressed or non-stressed. Multivariate Poisson regression with robust variance models of stress

15 status based on bicycling exposure, adjusting for potential confounders, were estimated.

Results: Bicycle commuters had significantly lower risk of being stressed [RR (95%CI) =

17 0.73 (0.60, 0.89), p-value=0.001]. Bicycle commuters who bicycled four or more days per

18 week had lower risk of being stressed than those who bicycled less than four days. This

19 relationship remained statistically significant after adjusting for individual and environmental

20 confounders, and when using a different cut-off of perceived stress.

Conclusions: Stress reduction may be an important consequence of routine bicycle use and

should be considered by decision makers as another potential benefit of its promotion.

2 3	1	STRENGHTS AND LIMITATIONS OF THIS STUDY
4 5 6	2	• The study had high internal validity, with a good representation of bicycle commuters.
7 8	3	• The study was conducted in Barcelona (a southern European city), adding evidence in
9 10	4	a different context than the current literature on these issues.
11 12	5	• The TAPAS Travel Survey sample is representative of Barcelona's population, taking
13 14 15	6	into account home neighbourhood deprivation and home and work population density.
15 16 17	7	• The study used a cross-sectional design, which is not well-suited to assess the
18 19	8	direction of causation.
20 21	9	• Using questionnaire data we could have misclassification error (information bias) of
22 23	10	bicycle commuting and physical activity because of the data being self-reported.
25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43	11	
44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60		For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml
INTRODUCTION

Walking and bicycling for transport is increasingly being promoted due to its potential for increasing physical activity (PA) levels in the general population (1-3). Active commuting – walking and bicycling for travel to and/or from work or educational addresses - has been associated with multiple health benefits from reductions to cardiovascular risk (4,5), lowering of body weight (2,5), improvement of fitness, reduced risk of diabetes (3), to higher levels of physical and mental well-being(6,7). Specifically, bicycle commuting has been inversely associated with all-cause mortality among both men and women in all age groups(8) and it seems to be likely to improve the health-related quality of life in previously untrained healthy adults(9). Active commuting has been shown to have other societal benefits such as helping reduce air pollution, greenhouse gas emissions, and noise, and improving social interaction(10).

Perceived stress is a global and comprehensive stress construct that refers to the interaction between the individual and the environment in the presence of a stressor(11). The perception of an event as stressful can result in a range of physiological, behavioural, and psychological changes, and can lead to cardiovascular disease, increased negative affect, lowered self-esteem, and lowered feelings of control. Hence, it is possible that mental health outcomes such as anxiety disorders and depression can be manifestations of chronic, perceived stress(12). Furthermore, others have suggested gender differences in stress-related variables. Women seem to be more physiologically reactive to social rejection challenges(13), are more likely to have daily stress, and be more impacted by life events(14).

24 Some literature recognises commuting as a potential source of stress(15); however, active

25 commuters have been shown to have higher levels of satisfaction, lower stress, higher

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relaxation and a heightened sense of freedom compared to car drivers(16–18). Recent qualitative research has suggested that commuting can be perceived as a relaxing or transitional time between home and work life, which can also be about enjoying pleasant landscape, nature and wildlife(19). Emerging literature has highlighted the relevance of positive natural and built environment to increase bicycle commuting and to improve mental health outcomes. Bicycle lane connectivity, bikeability, separation of bicycling from other traffic, high population density, short trip distance, proximity of a cycle path, green space and also walkability have been suggested as determinants of bicycling(20–24). Green space has also been associated with better self-perceived general health and better mental health(25,26). Several studies have examined the relationship between active commuting and commuting stress (stress directly related with the act of commuting)(17,18,27,28), but none of them have

13 studied the relationship between adult bicycle commuters and perceived stress, nor taking into

14 account environmental determinants. Moreover, most studies of active commuting benefits on

15 mental health have been conducted in North America or Northwest Europe, where the urban

16 design tends to be less dense than many parts of the world(6,7,17,28–30). Consequently, a

17 need exists to understand the relationship between bicycle commuting and perceived stress,

18 particularly in dense urban environments.

20 The current study aimed to evaluate the relationship between bicycle commuting among the

21 working or studying adult population and perceived stress in a dense urban setting.

1 MATERIALS AND METHODS

2 Study population

This cross-sectional study was based on participants from the Transportation, Air Pollution and Physical ActivitieS (TAPAS) Travel Survey. TAPAS is a relatively large study aimed at investigating the risks and benefits of active commuting. Participant recruitment was conducted by trained interviewers on the streets of Barcelona city between June 2011 and May 2012. To ensure adequate geographic coverage, a total of 40 random points (four random points within each of the ten city districts across Barcelona) were sampled. Adult bicycle commuters and non-bicycle commuters were asked in the street to answer a few screening questions, and those who fulfilled the inclusion criteria (being older than 18 years of age; living in Barcelona city since 2006 or earlier; working or going to school in Barcelona city; being healthy enough to ride a bicycle for 20 minutes; having a commute distance greater than a 10-minute walk; and using at least one mode of transport other than walking to commute) were invited to respond to a telephone survey. Bicycle commuters were oversampled to ensure enough bicycle commuters in the study. Those solely commuting on foot were excluded as the main interest was in the contrast between motorized modes (private and public transportation) and the bicycle. Of the 18469 participants approached across the forty sampling random points, 6701 agreed to answer screening questions. Of these, 1508 met the inclusion criteria, and 871 participants completed the survey. After survey responses were checked by the research team, 815 still fulfilled the inclusion criteria and 789 had geocodable home address. After excluding one PA outlier (total of all walking, moderate and vigorous time variables >960 minutes/day), 788 participants remained. Further details on the recruitment is given elsewhere(31).

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1	The study protocol was approved by the Clinical Research Ethical Committee of the Parc de
2	Salut Mar (CEIC-Parc de Salut Mar), and written informed consent was obtained from all
3	participants.
4	
5	Bicycle commuting
6	The TAPAS Travel Survey assessed the regular use of transport modes(32) and the bicycle
7	use(33). Participants who indicated using a bicycle (private or from public bicycle sharing
8	system) to go to work or school at least once the week prior to survey administration were
9	classified as "bicycle commuters". Participants who did not commute by bicycle in the week
10	prior to survey administration were classified as "non-bicycle commuters".
11	
12	As part of the sensitivity analyses, commuting behaviour was further classified according to
13	bicycle commuting levels and bicycle commuting propensity(24). Bicycle commuting levels
14	classification was based on the days of bicycle commuting in the week prior to survey
15	administration: "low" being three days or fewer, "medium" for four days, and "high" for five
16	or more days. This measure could be interpreted as a proxy of bicycle commuting frequency.
17	Bicycle commuting propensity classification took into account both frequency and
18	willingness to commute by bicycle: the "bicycle commuters" were further classified as
19	"frequent" (four or more days) or "infrequent" (three or less days), and the "non-bicycle
20	commuters" were classified as "willing" or "unwilling". The "willing" group were those
21	"non-bicycle commuters" who indicated bicycling as "never or nearly never" their general
22	transport mode, but who also indicated that they would consider bicycle commuting in
23	Barcelona (they answered positively to "considering costs, travelling time, comfort and
24	safety, how ready would you be to use the bicycle/Bicing (public bicycle-sharing system) for
25	your trip to work or education centre?"). The "unwilling" group were those "non-bicycle

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commuters" who indicated "never or nearly never" bicycling for travel and indicated that they
 would not consider bicycle commuting in Barcelona by answering negatively to the above
 question. More details of the bicycle commuting propensity classification are given
 elsewhere(24). This measure was included in the analysis to assess the effect of being willing
 to commute by bicycle in perceived stress.

7 Perceived stress

The last four questions of the TAPAS Travel Survey were the short version of Perceived Stress Scale (PSS-4)(11), which is a well-validated psychological instrument to measure the degree to which situations in one's life over the past month are appraised as stressful. The instrument contains four statements, which measure how unpredictable, uncontrollable, and overloaded respondents feel that their lives are (Table S1). The higher the score on the PSS-4 (from 0 to 16), the greater the respondent perceives that their demands exceed their ability to cope. There are no cut-off scores. Instead, an individual's score is compared to a normative value(34). In the TAPAS Travel Survey the 5-point Likert scale was modified to a 4-point Likert scale, removing the midpoint option for consistency with other questions in the survey, as all other questions used a 4-point Likert scale. The sample did not have high levels of perceived stress (Table S2); therefore, for an easier interpretation, participants with a PSS-4 score higher than 3 (median of the total sample) were classified as "stressed", and those equal or lower than 3 were classified as "non-stressed". The sensitivity of our results to this choice was examined further in sensitivity analyses by classifying the respondents with PSS-4 scores in the 75th percentile (P75) and above (a score higher than 4) and in the 90th percentile (P90) and above (a score of 6 and above) as stressed and all others as non-stressed.

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1 **Other explanatory measures**

Individual determinants of bicycle commuting and perceived stress such as physical activity 3 levels(35), socio-demographic variables, and work or school addresses were also derived from 4 the TAPAS Travel Survey to be used as potential confounders. In addition, the MEDEA 5 Index (Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómicas y 6 Ambientales, in Spanish; Environmental and socioEconomic Inequalities in Mortality in small 7 Spanish areas, translated to English) was used as an area deprivation indicator assigned to 8 each participants' address. MEDEA measures deprivation at the census tract level based on 9 five domains including percentage of manual workers, temporary workers, total population 10 with low education, young population with low education, and unemployment(36). 11 12 Environmental determinants of bicycle commuting and perceived stress within a 400m buffer 13 surrounding home and work/study addresses, and a Route-By-Area (RBA) surrounding 14 predicted commute routes, were calculated to be used as potential confounders too. The 15 number of public bicycle stations within a 400m buffer surrounding home and work/study 16 addresses was calculated based on information from the Ajuntament de Barcelona -17 Informació de Base i Cartografia (IBC) (Barcelona City Council – Basic information and 18 mapping). Greenness was calculated as a mean in Normalized Difference Vegetation Index 19 (NDVI) via satellite imagery (LANDSAT 4 and 5, NASA). Mean NO₂ levels were estimated 20 using a land-use regression model developed for a previous project(37). Noise was calculated 21 as the proportion of street length above a 55 dB(A) threshold(38). A bikeability index was 22 calculated taking into account five factors shown to influence bicycling: bicycle facility 23 availability, bicycle facility quality, street connectivity, topography, and land use(39). 24 Commute distance did not use buffers and it was calculated in km following the street

network of the shortest route from home address to work address. Further details of the
 environmental determinants calculation are given elsewhere(24).

Statistical analyses

A Generalized Additive Model (GAM) was used to test linearity between perceived stress and total physical activity (Total PA), moderate-to-vigorous physical activity (MVPA), vigorous physical activity (VPA), and age(40). As there was no statistical evidence to reject linearity between perceived stress and Total PA (p-value = 0.3816), MVPA (p-value = 0.5025), VPA (p-value = 0.1630), and age (p-value = 0.2282), these variables were included as continuous variables in the model assuming a linear relationship. Multivariate Poisson regression with robust variance models were used to assess the relationship between bicycle commuting and perceived stress. Possible mediation by different levels of PA between bicycle commuting and perceived stress, and any interaction between gender and bicycle commuting were also tested with Poisson regression with robust variance models. All regression models were conducted with a complete case analysis and included individual and environmental potential confounders that showed a p-value < 0.05 in the bivariate analysis as well as those found to be statistically significant within previous literature. The first descriptive statistical analyses were conducted in Stata version SE 12 (StataCorp LP, Texas USA), while Poisson regression with robust variance models were conducted in Stata version SE 14 (StataCorp LP, Texas USA).

RESULTS

The included sample had an equal distribution of genders and the median age (P25-P75) was 36 (29-43) years (Table 1). The majority of participants were non-stressed (had a stress score equal or lower than 3), Spanish, possessing university studies completed or equivalent-level education, living with their family or partner, living with at least 2 employed people and not Page 11 of 34

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1	with children (64.34%). Among those living with children, 8.12% had children younger than
2	3 years of age. The sample had positive self-perception of health (with only $<1\%$ of
3	participants self-perceiving bad or very bad health), healthy weight according to BMI
4	(71.12%), and generally no chronic disease (92.26%). Bicycle commuters were statistically
5	significant more likely to be non-stressed; younger (35 years); men; have higher levels of PA;
6	possess a university or equivalent-level education; live alone and/or with flat mates with 0-1
7	employed people; have no children; and have better self-perception of health, and healthy
8	weight, but more chronic diseases than non-bicycle commuters. The majority of participants
9	considered that they could release stress when riding a bicycle and that they enjoyed their trip
10	more if they used a bicycle. Bicycle commuters had shorter commutes compared to non-
11	bicycle commuters, and we observed a gradient between commute distance and bicycle
12	commuting levels with shorter distances for those who cycled more frequently. This tendency
13	was also followed by bicycle commuting propensity, with decreasing commute distance from
14	unwilling to bicycle to frequent bicyclists (Table S3). Bicycle commuters also had more
15	public bicycle stations around the home and work/study addresses, lower average greenness
16	around the home address, and higher levels of bikeability at home, work/study address, and
17	on the commute route compared to non-bicycle commuters (Table 1). These environmental
18	determinants stayed statistically significant for bicycle commuting propensity, but not
19	between bicycle commuting levels (Table S3).
20	
21	Women, non-Spanish, those living with 0-1 employed people, and those having a chronic

disease were more likely to be stressed (Table 2). Participants who had more public bicycle
stations around their work/study area and higher levels of bikeability in the work/study

- 24 address area and on the commute route were less likely to be stressed. There was no
- 25 statistically significant relationship between commute distance, greenness, NO₂ and noise, and

- 1 perceived stress. The possible mediation of PA was not further explored as there was no
- 2 statistically significant relationship between levels of PA (Total PA, MVPA and VPA) and
- 3 perceived stress for the three different classifications of perceived stress (P50, P75, P90) [RR
- 4 (95% CI): 1.00 (0.99, 1.00), all p-values>0.10] (Table 2, Table S4).

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1 Table 1. Descriptive analyses of perceived stress and determinants of participants and

2 according to bicycle commuting status.

	Total	sample (788)	Bicycle commuting status					
Variables	Total sample (700)		Non-bicycle	commuters (390)	Bicycle co	n-value ^a		
	n	%	n	%	n	%	P	
Outcome								
Stressed (median) (Yes)	280	35.53	162	41.97	118	30.33	0.001	
Sitessed (incutail) (103)	200	00.00	102		110	50.55	0.001	
Individual determinants								
Age (median; P25-P75)	36	29-43	37	30-45	35	29-41	0.025	
Total PA – min/week (median; P25-P75)	424.99	269.99-700.00	374.99	209.99-624.99	484.98	329.99-734.99	< 0.001	
MVPA – min/week (median; P25-P75)	197.49	72.50-374.99	90.00	0-40	299.99	159.99-464.99	< 0.001	
VPA – min/week (median; P25-P75)	72.50	0-180.00	35.00	0-134.99	105.00	0-225.00	< 0.001	
Gender (Woman)	410	52.03	234	60.00	176	44.22	< 0.001	
Country of birth (non-Spanish)	97	12.31	41	10.51	56	14.11	0.125	
Working status (Student)	104	13.20	347	87.19	51	12.81	0.748	
equivalent-level (University studies completed or equivalent-level education)	551	69.92	247	63.33	304	76.38	< 0.001	
Living with family/partner	635	80.58	327	83.85	308	77.58	0.026	
Employed people in household (2-5)	510	64.72	261	67.27	249	62.88	0.198	
MEDEA index							0.355	
1st tertile (least deprived)	263	33.38	130	33.33	133	33.42		
2nd tertile	263	33.38	122	31.28	141	35.43		
3rd tertile (most deprived)	262	33.25	138	35.38	124	31.16		
Children in household (Yes)	279	35.41	151	38.82	128	32.24	0.054	
Children <3 years in household (Yes)	64	8.12	36	9.25	28	7.07	0.264	
Self-perceived health (Very good/Excellent)	323	40.99	140	35.90	183	45.98	0.004	
BMI (Overweight/Obese)	212	26.9	124	31.96	88	22.11	0.002	
Chronic disease (Yes)	61	7.74	25	0.41	30 256	9.05	0.100	
Stress releasing (Agreement)	620	83.30	302	(9.4)	330	90.39	<0.001	
Bicycle trip enjoyment (Agreement)	029	19.82	249	05.55	380	90.20	<0.001	
Environmental determinants								
	2.95	2.05	4 28	2.25	2.25	1.70	<0.001	
Commute distance estimated (km) (mean SD)	5.65	2.03	4.38	2.23	3.33	1.70	<0.001	
Public bioucle stations (mean SD)								
Hama accurt in 400m huffer	4.25	2.54	2.75	2.51	4 75	2.47	<0.001	
	4.23	2.34	3.73	2.51	4.73	2.47	<0.001	
work/study, count in 400m buffer	4.92	3.11	4.50	3.13	5.33	3.04	~0.001	
Greenness, NDVI [IQR, (mean;SD)]				1.00	0.60			
Home, average of 400m buffer	0.79	1.07	0.91	1.08	0.68	1.06	< 0.001	
Work/study, average of 400m buffer	0.62	0.96	0.70	1.07	0.55	0.83	0.086	
Commute route, average of RBA	0.97	0.96	1.07	1.06	0.87	0.85	0.062	
NO ₂ , ppb (mean;SD)								
Home, concentration in 400m buffer	76.20	17.52	75.16	17.12	77.21	17.87	0.058	
Work/study, concentration in 400m buffer	78.43	22.51	78.56	23.92	78.31	21.10	0.843	
Commute route, concentration in RBA	84.40	16.97	84.24	16.82	84.55	17.13	0.987	
Noise, >55dB (%) (mean:SD)								
Home proportion in 400m buffer	78.63	11.40	78.77	10.99	78.50	11.79	0.823	
Work/study, proportion in 400m buffer	79.59	14.66	79 09	14 86	80.07	14 46	0 369	
Commute soute anne stien in DDA	77.40	9.04	77.51	8 58	77 30	9.48	0.924	
Commute route, proportion in KBA	77.40	2.04	11.31	0.50	11.50	2.40	0.924	
Bikeability (mean;SD)	<i>(</i> 2 0	1.41	C 02	1.45	<i></i>	1.21		
Home, concentration in 400m buffer	6.20	1.41	5.93	1.45	6.46	1.31	< 0.001	
Work/study, concentration in 400m buffer	6.56	1.39	6.31	1.54	6.79	1.17	< 0.001	
Commute route, concentration in RBA	6.70	1.12	6.45	1.20	6.94	0.98	< 0.001	

PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; MEDEA, Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómic nequalities in Mortality in small Spanish areas, translated to English); BMI, Body Mass Index; NDVI, Normalized Difference Vegetation Index; RBA, Route-By-Area. Data are na nad %, unless otherwise noted. There are missing data in: Perceived Stress (13; 1.65%), Total PA, Route-By-Area. Data are na nad %, unless otherwise noted. There are missing data in: Perceived Stress (13; 1.65%), Total PA (5; 0.63%), Country of birth (1; 0.13%), Living with family/partner (1; 0.13%), Employed people in household (4; 0.51), Children in household (2; 0.25%), Children <3years old in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂(20; 2.54%). "Chi square test, except for Age, Total PA, MVPA, VPA, and all the Environmental determinants (U Mann Whitney test)."

Table 2. Bivariate analyses showing the relationships between perceived stress (median) and

determinants of participants.

Variahla	Perceived stress				
variable	RR	p-value			
Individual determinants					
Age	1.00	(0.99, 1.01)	0.502		
Total PA - min/week	1.00	(0.99, 1.01)	0.669		
MVPA - min/week	1.00	(0.99, 1.00)	0.114		
VPA - min/week	1.00	(0.99, 1.00)	0.658		
Gender (Woman)	1.55	(1.27, 1.89)	<0.001		
Country of hirth (Spain)	1 34	(1.27, 1.09) (1.05, 1.70)	0.017		
Working status (Student)	1 22	(0.95, 1.76)	0.115		
Education level (University studies completed	1.22	(0.95, 1.50)	0.115		
or Others)	0.92	(0.75, 1.12)	0.387		
Living with family/partner	0.91	(0.73, 1.12)	0 439		
Employed people in household (2-5)	0.74	(0.62, 0.90)	0.002		
MEDEA index	0.71	(0.002		
1st tertile (least deprived)	1.00				
2nd tertile	1.08	(0.85, 1.37)	0.537		
3rd tertile (most deprived)	1.18	(0.94, 1.48)	0.162		
Children in household (Yes)	0.90	(0.74, 1.10)	0.330		
Children <3 years in household (Yes)	0.90	(0.60, 1.27)	0.475		
Self-perceived health (Very good/Excellent)	0.87	(0.00, 1.27) (0.71, 1.06)	0.157		
BMI (Overweight/Ohese)	0.95	(0.77, 1.18)	0.669		
Chronic disease (Yes)	1 38	(1.04, 1.83)	0.024		
Stress releasing (Agreement)	0.87	(0.68, 1.11)	0.273		
Bicycle trin enjoyment (Agreement)	0.91	(0.00, 1.11) (0.72, 1.14)	0.425		
Bieyele trip enjoyment (Agreement)	0.91	(0.72, 1.11)	0.120		
Environmental determinants					
Commute distance, estimated (km)	1.02	(0.97, 1.06)	0.508		
Public bicycle stations					
Home, count in 400m buffer	0.99	(0.95, 1.02)	0.503		
Work/study, count in 400m buffer	0.96	(0.93, 0.99)	0.024		
Greenness, NDVI		()			
Home, average of 400m buffer	0.94	(0.85, 1.05)	0.258		
Work/study, average of 400m buffer	1.06	(0.96, 1.16)	0.241		
Commute route, average of RBA	0.99	(0.89, 1.09)	0.838		
NO ₂ ppb					
Home, concentration in 400m buffer	1.00	(0.99, 1.01)	0.827		
Work/study, concentration in 400m buffer	1.00	(0.99, 1.00)	0.100		
Commute route, concentration in RBA	1.00	(0.99, 1.00)	0.518		
Noise, >55dB					
Home, proportion in 400m buffer	1.00	(0.98, 1.00)	0.363		
Work/study, proportion in 400m buffer	1.01	(0.99, 1.01)	0.125		
Commute route, proportion in RBA	1.00	(0.98, 1.01)	0.405		
Bikeability					
Home, concentration in 400m buffer	1.00	(0.94, 1.07)	0.931		
Work/study, concentration in 400m buffer	0.92	(0.86, 0.98)	0.009		
Commute route, concentration in RBA	0.91	(0.84, 0.98)	0.018		

PA, Physical Activity; WPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; MEDEA, Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómicas y Ambientales, in Spanish (Environmental and socioEconomic Inequalities in Mortality in small Spanish areas, translated to English); BMI, Body Mass Index, NDVI, Normalized Difference Vegetation Index; RBA, Route-By-Area. Complete case analysis excluding missing data of the variables of final models (Table 3; n=771). The variables that still present missing data and are not included in the final models are: Total PA (5; 0.63%), People living with in household (1; 0.13%), Children in household (2; 0.25%), Children <3 per source of in a nodels are: Total PA (5; 0.63%), People living with in household (2; 0.25%), Children <3 per source of a star of a

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1	Multivariate Poisson regression with robust variance analyses showed a statistically
2	significant inverse relationship between bicycle commuting and perceived stress. Bicycle
3	commuters had a lower risk of being stressed compared to non-bicycle commuters [RR
4	(95%CI) = 0.73 (0.60, 0.89), p-value=0.001]. This relationship remained after adjusting for
5	confounders (individual and environmental) and when using P75 and P90 perceived stress
6	cut-offs (Table 3, Table S5). There was a statistically significant inverse relationship between
7	medium and high levels of bicycle commuting and perceived stress using non-bicycle
8	commuters as a reference group [RR (95%CI) = 0.46 (0.28, 0.78), p-value=0.004; RR
9	(95%CI) = 0.63 (0.49, 0.81), p-value<0.001] and also when using low levels of bicycle
10	commuting [RR (95%CI) = 0.42 (0.24, 0.73), p-value=0.002; RR (95%CI) = 0.57 (0.42,
11	0.77), p-value<0.001] as a reference group. This statistically significant relationship remained
12	in the majority of sensitivity analyses. Regarding bicycle commuting propensity, there was a
13	statistically significant inverse relationship between frequent bicycle commuters and
14	perceived stress, using unwilling non-bicycle commuters [RR (95%CI) = 0.53 (0.41, 0.67), p-
15	value<0.001] and infrequent bicycle commuters [RR (95%CI) = 0.54 (0.40, 0.72), p-
16	value<0.001] as respective reference groups. The statistically significant relationship
17	remained after adjusting for individual and environmental confounders and when using
18	perceived stress P75 and P90 as cut-offs. Also, there was a statistically significant inverse
19	relationship between willing non-bicycle commuters and perceived stress, using unwilling
20	non-bicycle commuters [RR (95%CI) = 0.72 (0.56, 0.94), p-value=0.014] as a reference group
21	in the bicycle commuting propensity variable and also looking only in the non-bicycle
22	commuting group [RR (95%CI) = 0.72 (0.56, 0.94), p-value=0.015]. This relationship
23	remained after adjusting for individual and environmental confounders, but not when using
24	perceived stress at the P75 and P90 cut-offs.
25	

- 1 In the fully adjusted models, we found no statistically significant interactions between gender
- 2 and bicycle commuters (p-value= 0.165) between gender and bicycle commuting levels (p-
- 3 value=0.226, p-value=0.266, p-value=0.431), or between gender and bicycle commuting
- 4 propensity (p-value=0.982, p-value=0.197, p-value=0.277) (results not shown).

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Table 3. Multivariate models showing the relationships between bicycle commuting and perceived stress (median) of participants.

	Perceived stress											
Variable	RR Unadjusted (95% CI)		p-value	RI	RR Adjusted ^a (95% CI)		RR Adjusted ^b (95% CI)		p-value	RR Adjusted ^c (95% CI)		p-value
All sample (771)												
Bicycle commuting status												
Non-bicycle commuters	1.00			1.00			1.00			1.00		
Bicycle commuters	0.73	(0.60, 0.89)	0.001	0.75	(0.62, 0.91)	0.003	0.77	(0.63, 0.94)	0.009	0.80	(0.66, 0.99)	0.036
Bicycle commuting levels												
Non-bicycle commuters (0 days)	1.00			1.00			1.00			1.00		
Low bicycle commuting (1-3 days)	1.10	(0.87, 1.39)	0.436	1.11	(0.88, 1.40)	0.369	1.13	(0.89, 1.44)	0.297	1.17	(0.92, 1.48)	0.205
Medium bicycle commuting (4 days)	0.46	(0.28, 0.78)	0.004	0.45	(0.27, 0.74)	0.002	0.45	(0.27, 0.75)	0.002	0.48	(0.29, 0.80)	0.005
High bicycle commuting (>=5 days)	0.63	(0.49, 0.81)	< 0.001	0.66	(0.51, 0.85)	0.001	0.68	(0.52, 0.88)	0.003	0.71	(0.54, 0.92)	0.010
Bicycle commuting propensity												
Unwilling Non-bicycle commuters	1.00			1.00			1.00			1.00		
Willing Non-bicycle commuters	0.72	(0.56, 0.94)	0.014	0.75	(0.58, 0.97)	0.029	0.74	(0.57, 0.96)	0.022	0.75	(0.58, 0.97)	0.031
Infrequent Bicycle commuters	0.98	(0.76, 1.25)	0.847	1.00	(0.78, 1.27)	0.980	1.01	(0.79, 1.30)	0.940	1.04	(0.81, 1.34)	0.739
Frequent Bicycle commuters	0.53	(0.41, 0.67)	< 0.001	0.55	(0.43, 0.70)	< 0.001	0.56	(0.43, 0.72)	< 0.001	0.58	(0.45, 0.76)	< 0.001
Bicycle commuters sample (387)												
Bicycle commuting levels												
Low bicycle commuting (1-3 days)	1.00			1.00			1.00			1.00		
Medium bicycle commuting (4 days)	0.42	(0.24, 0.73)	0.002	0.39	(0.23, 0.67)	0.001	0.39	(0.23, 0.65)	< 0.001	0.38	(0.23, 0.65)	< 0.001
High bicycle commuting (>=5 days)	0.57	(0.42, 0.77)	< 0.001	0.59	(0.44, 0.80)	0.001	0.59	(0.44, 0.80)	0.001	0.59	(0.44, 0.80)	0.001
Bicycle commuters propensity												
Infrequent (1-3 days)	1.00			1.00			1.00			1.00		
Frequent (>=4 days)	0.54	(0.40, 0.72)	< 0.001	0.55	(0.41, 0.73)	< 0.001	0.54	(0.41, 0.72)	< 0.001	0.54	(0.41, 0.72)	< 0.001
Non-bicycle commuters sample (384)												
Non-bicycle commuters												
Unwilling	1.00			1.00			1.00			1.00		
Willing	0.72	(0.56, 0.94)	0.015	0.73	(0.57, 0.95)	0.020	0.72	(0.56, 0.93)	0.013	0.74	(0.57, 0.95)	0.020

³ Adjusted by Gender, Country of birth, Employed people in household, Chronic disease. ^bAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). ^cAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). ^cAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). ^cAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). ^cAdjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, MVPA, Public bicycle stations at work/study, Bikeability at commute route.

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DISCUSSION

2 Summary of results

We evaluated relationships between bicycle commuting and perceived stress while adjusting for several confounders in a representative sample of adults in Barcelona, Spain. We found statistically significant inverse relationships between several measures of bicycle commuting and perceived stress. Bicycle commuters who bicycled four or more days per week had lower risk of being stressed compared to those who cycled less or did not bicycle on their commute. This relationship remained statistically significant in all sensitivity analyses and after controlling for individual and environmental confounders.

11 Comparison with previous studies

To our knowledge, this study is the first to assess whether a relationship exists between bicycle commuting and perceived stress. A few studies have focused on the relationship between active commuting and mental health(6,7,29), but the relationship is still unclear. One study found a positive association between active commuting and well-being(6), and another with better mental health in men(29). Moreover, Humphreys(7) found a positive relationship between time spent actively commuting and levels of physical well-being, but not with mental well-being. The relationship between physical activity and mental health has been studied more. It has been suggested that physical activity could reduce stress and anxiety on a daily basis while improving self-perception and mood(41-43), and it has been associated with lower depressive symptomatology and greater emotional well-being(44). These findings suggest that the physical activity gained during bicycle commuting(31) may act as a mediator in the relationship between bicycle commuting and perceived stress. Our results are consistent with the general idea that active commuting is associated with better mental health, but in our

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1	case physical activity did not act as a mediator in this relationship. Our sample was
2	composed of young, healthy, and active participants with low levels of perceived stress,
3	which might have led to an underestimation of the relationship between PA and perceived
4	stress.
5	
6	Qualitative research suggested that choice of travel mode may affect well-being(19). The
7	quantity of public bicycle (Bicing) stations and the amount of greenness has been related to
8	bicycle commuting propensity(24), which could imply that commuting by bicycle provides
9	people with more opportunities to "enjoy" or "experience" greenness than commuting on
10	public transport or a car. At the same time, the availability of green space close to one's home
11	has been shown to be related to better self-perceived general health and better mental
12	health(25,26,45). Therefore, it seems that perceptual and environmental factors related to
13	bicycle commuting could affect perceived stress, in the way that more pleasant an
14	environment to bicycle commute is, better perceived stress results we will get. This general
15	idea is consistent with our results which show an inverse relationship between perceived
16	stress and bicycle-friendly environments (public bicycle stations and bikeability levels) in
17	work/study address area and the commute route. Importantly, the relationship between
18	bicycling and stress was unchanged after controlling for the environmental confounders. Our
19	results also showed that general attitude might have a role in this relationship, as we have seen
20	that those willing non-bicycle commuters, compared to unwilling non-bicycle commuters,
21	were less stressed. But this remained quite unclear as the relationship becomes statistically no
22	significant in the sensitivity analyses.

2 Limitations and strengths

Our study had some limitations. Firstly, our study used a cross-sectional design, which is not well-suited to assess the direction of causation, and we cannot exclude reverse causality or residual confounding. It has been suggested that stressed people can engage in unhealthy behaviours, such as poor dietary practices or a lack of physical activity (46). This reasoning could be applied to a behaviour like bicycle commuting, where those individuals who are more stressed would bicycle less. Secondly, our measurement method may be prone to information bias. With the questionnaire data we could have random misclassification error of bicycle commuting and PA because of the data being self-reported. Therefore, the risk estimate and also the potential mediation by PA could be under-estimated(47). The TAPAS Travel Survey only measured levels of PA without differentiating between types of PA (work, travel, recreational). Furthermore, the modification of the 5-point PSS-4 Likert scale into a 4-point Likert scale could incorrectly-estimate the perceived stress.

This study had several strengths, too. The study had high internal validity, with a good representation of bicycle commuters. Related to participants' characteristics, the TAPAS Travel Survey sample is representative of Barcelona's population from the socio-demographic point of view. It was compared with data from the Catalan government's Barcelona Active Population Survey (Statistics and information service, Catalan government 2011) and no statistically significant differences between participants' deprivation index and home and work population density in both surveys were found(24,31). Finally, our study in a southern European city has added evidence in a different context than the current literature on these issues.

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1 Future research

Our findings underscored the need for future research. There is a need to obtain a clear understanding of the relationship between the bicycle commuting and perceived stress in longitudinal studies. The role of PA in this relationship seems unclear, and it is likely that other factors could affect the relationship between these two variables, especially those related to environmental determinants and personal attitudes. Further work related to determinants and mediators of bicycle commuting and perceived stress is needed.

8 CONCLUSIONS

We found that healthy, adult bicycle commuters had lower risk of being stressed than commuters of other transport modes. Also, bicycle commuters who bicycled four or more days per week had lower risk of being stressed than those who bicycled less than that. Environmental determinants such as the number of public bicycle stations and bikeability, and also personal attitudes seem to have an influence on this relationship. Further research is needed in order to disentangle the relationship between bicycle commuting and perceived stress, and its determinants (individual and environmental) and potential mediators. Our findings suggest that decision-makers may promote bicycle commuting as a daily routine, to reduce stress levels and improve public health and well-being.

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13 No conflicts of interest were reported by the authors of this paper.

14 AUTHOR'S CONTRIBUTION

15 MJN and AdN obtained the funding and designed the study. IAP conducted the analyses and

16 drafted this version of the paper and received input from all the authors. All authors read and

17 commented on the paper and agreed with the final version.

18 DATA SHARING

19 Extra data is available by emailing the corresponding author (Ione Avila-Palencia:

20 ione.avila@isglobal.org).

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25	

SUPPLEMENTARY MATERIAL

Table S1. PSS4 questions used in TAPAS Travel Survey

Q218. In the last month, how often have you felt that you were unable to control important things in your life?

0	Never
1	Almost never
2	Nearly always
3	Always
997	Don't Know
998	Refuse to Answer

Q219. In the last month, how often have you felt confident about your ability to handle your personal problems?

0	Never
1	Almost never
2	Nearly always
3	Always
997	Don't Know
998	Refuse to Answer

Q220. In the last month, how often have you felt that things were going your way?

0	Never
1	Almost never
2	Nearly always
3	Always
997	Don't Know
998	Refuse to Answer

Q221. In the last month, how often have you felt that difficulties were piling up so high that you could not overcome them?

0	Never
1	Almost never
2	Nearly always
3	Always
997	Don't Know
998	Refuse to Answer

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PSS-4 score	n	%	Cumulative %
0	90	11.61	11.61
1	125	16.13	27.74
2	129	16.65	44.39
3	151	19.48	63.87
4	144	18.58	82.45
5	38	4.90	87.35
6	33	4.26	91.61
7	12	1.55	93.16
8	28	3.61	96.77
9	5	0.65	97.42
10	11	1.42	98.84
11	3	0.39	99.23
12	4	0.52	99.74
13	1	0.13	99.87
14	1	0.13	100.00
Total	775	100.00	

Table S2. PSS4 score distribution in TAPAS Travel Survey sample

Table S3. Description of the individual and environmental determinants in TAPAS

sample for Bicycle commuting levels and Bicycle commuting propensity.

9																	
10				Bicy	cle commuting	g levels						Bicycle co	ommuting	propensity			
11	Variables		Low (109)	Me	dium 65)	H (2	ligh (24)		U	nwilling (230)	1	Willing (160)	Infree	quent (109)	Fi	requent (289)	
12		n	%	n	%	n	%	p-value	n	%	n	%	n	%	n	%	p-value
13	Outcome																
14	Stressed (median)(Yes)	49	45.37	12	19.05	57	26.15	< 0.001	107	46.93	55	34.81	49	45.37	69	24.56	< 0.001
15	Individual determinants																
16	Age (median; P25-P75)	36	28-42	36	28-45	35	29-41	0.777	37	30-46	36	29.5-45	36	28-42	35	29-41	0.111
17	Total PA - min/week (median; P25-P75)	494.99	299.99-734.99	454.99	359.99- 689.99	484.99	339.99- 779.99	0.567	364.99	209.99-600.00	404.99	209.99-629.99	494.99	299.99-734.99	480.00	339.99-744.99	< 0.001
18	MVPA - min/week (median; P25-P75)	240.00	134.99-480.00	294.99	390.00	300.00	479.99	0.092	90.00	0-244.99	90.00	0-240.00	240.00	134.99-480.00	300.00	179.99-450.00	< 0.001
19	VPA - min/week (median; P25-P75)	120.00	0-224.99	90.00	0-199.99	102.50	0-240.00	0.386	45.00	0-150.00	0	0-127.50	120.00	0-224.99	90.00	225.00	< 0.001
20	Gender (Woman)	49	44.95	33	50.77	94	41.96	0.446	151	65.65	83	51.88	49	44.95	127	43.94	< 0.001
20	Country of birth (non-Spanish)	19	17.59	7	10.77	30	13.39	0.412	16	6.96	25	15.63	19	17.59	37	12.80	0.014
21	Working status (Student)	17	15.60	10	15.38	24	10.71	0.364	24	10.43	29	18.13	17	15.60	34	11.76	0.112
22	Education level (University studies completed or equivalent-level education)	81	74.31	50	76.92	173	77.23	0.836	161	70.00	86	53.75	81	74.31	223	77.16	< 0.001
23	Living with family/partner	88	80.73	48	75.00	172	76.79	0.622	192	83.48	135	84.38	88	80.73	220	76.39	0.114
24	Employed people in household (2-5)	69	63.30	35	55.56	145	64.73	0.410	152	66.09	109	68.99	69	63.30	180	62.72	0.568
25	MEDEA index							0.627									0.660
26	1st tertile (least deprived)	35	32.11	23	35.38	75	33.48		81	35.22	49	30.63	35	32.11	98	33.91	
20	2nd tertile	38	34.86	27	41.54	76	33.93		66	28.70	56	35.00	38	34.86	103	35.64	
27	3rd tertile (most deprived)	36	33.03	15	23.08	73	32.59		83	36.09	55	34.38	36	33.03	88	30.45	
28	Children in household (Yes)	31	28.44	18	28.13	79	35.27	0.340	94	40.87	57	35.85	31	28.44	97	33.68	0.128
29	Children <3 years in household (Yes)	3	2.75	5	7.94	20	8.93	0.114	20	8.73	16	10.00	3	2.75	25	8.71	0.158
30	Self-perceived health (Very good/Excellent)	43	39.45	27	41.54	113	50.45	0.123	90	39.13	50	31.25	43	39.45	140	48.44	0.004
21	BMI (Overweight/Obese)	25	22.94	14	21.54	49	21.88	0.969	73	31.88	51	32.08	25	22.94	63	21.8	0.021
21	Chronic disease (Yes)	11	10.09	8	12.31	17	7.59	0.458	18	7.83	7	4.38	11	10.09	25	8.65	0.293
32	Stress releasing (Agreement)	95	87.16	62	98.41	199	90.05	0.047	163	72.44	139	89.68	95	87.16	261	91.90	< 0.001
33	Bicycle trip enjoyment (Agreement)	103	94.50	65	100.00	212	95.93	0.175	116	51.79	133	84.71	103	94.50	277	96.85	< 0.001
34																	
35	Environmental determinants																
36	Commute distance, estimated (km) (mean;SD)	3.73	1.97	3.43	1.70	3.13	1.52	0.044	4.42	2.35	4.32	2.11	3.73	1.97	3.20	1.56	< 0.001
20	Public bicycle stations (mean;SD)																
37	Home, count in 400m buffer	4.61	2.61	4.97	2.63	4.75	2.35	0.492	3.77	2.53	3.72	2.49	4.61	2.61	4.80	2.41	< 0.001
38	Work/study, count in 400m buffer	4.89	2.96	5.89	3.11	5.39	3.05	0.124	4.36	2.96	4.71	3.35	4.89	2.96	5.50	3.06	<0.001
39	Greenness, NDVI (mean;SD)																
40	Home, average of 400m buffer	0.83	1.30	0.75	0.98	0.59	0.94	0.635	0.90	1.03	0.91	1.16	0.83	1.30	0.62	0.95	0.002
11	Work/study, average of 400m buffer	0.60	0.82	0.37	0.57	0.58	0.90	0.136	0.68	1.11	0.74	1.01	0.60	0.82	0.53	0.84	0.328
41	Commute route, average of RBA	0.95	0.94	0.76	0.83	0.87	0.81	0.322	1.10	1.11	1.02	0.98	0.95	0.94	0.84	0.81	0.236
42	NO2 ppb (mean;SD)	74.76	19.70	77.04	16.14	78.40	17.00	0.100	75.50	17.09	74.51	17.00	74.76	10.70	70.14	17.40	0.062
43	Home, concentration in 400m buffer	74.70	18.70	11.24	10.14	78.40	17.90	0.180	79.59	17.08	74.51	17.20	74.70	18.70	78.14	17.49	0.063
44	Work/study, concentration in 400m buffer	/0.49	21.05	83.02	18.82	//.81	21.37	0.197	/8.50	25.84	/8.04	24.11	/6.49	21.05	79.00	20.90	0.727
45	Commute route, concentration in RBA	82.80	16.10	87.47	15.22	84.51	18.08	0.127	85.22	17.54	82.70	15.95	82.80	16.10	85.19	17.48	0.296
16	Noise, >55dB (mean;SD)	70 72	12.20	77.65	0.77	79 62	11.54	0.554	70.02	11.00	79.20	11.01	70 72	12 20	79.41	11.16	0.847
47	Home, proportion in 400m buffer	10.13	13.39	11.00	9.//	70.22	11.34	0.354	79.03	11.00	18.39	12.04	16.15	13.39	70.49	11.10	0.424
4/	Work/study, proportion in 400m buffer	01.04 78.40	0.12	75 40	15.80	19.32	0.64	0.408	77.12	9.42	70.00	9 70	01.04 78 40	13.00	76 90	14./3	0.454
48	Commute route, proportion in RBA	/0.02	9.13	/3.40	9.20	11.21	9.04	0.057	11.12	0.43	78.08	o./ð	/ 6.02	9.13	70.80	9.37	0.100
49	Bikeability (mean;SD)	6 20	1.44	6 40	1.22	6 51	1.07	0.220	5 00	1.45	6.00	1.45	6.20	1.44	6 57	1.24	<0.001
50	Home, concentration in 400m buffer	6.02	1.44	6.00	1.23	6.75	1.27	0.550	5.88	1.40	6.44	1.45	6.29	1.44	6.79	1.20	<0.001
51	Work/study, concentration in 400m buffer	6.77	1.20	7.02	0.98	6.00	0.93	0.036	6.36	1.30	6.58	1.47	6.77	1.20	7.00	0.03	<0.001
51	Commute route, concentration in RBA PA Physical Acti	vitv M	VPA Moderat	e-to-Vigor	ous Physical	Activity: V	VPA Vigoro	us Physical	Activity: 1	MEDEA Mort	o.Jo alidad en	áreas nequeñas	Esnañol	as v Designal	lades	0.93	<0.001
52	TA, Thysical Acti		· · · · · · · · · · · ·	the form	sas i nysical	Leaving,	· · · · , vigol0	as i nysical i			uuu Ull	Leas pequends	-Lopanon	De la Mara I			

PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; MEDEA, Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómicas y Ambientales, in Spanish (Environmental and socioEconomic Inequalities in Mortality in small Spanish areas, translated to English); BMI, Body Mass Index; NDVI, Normalized Difference Vegetation Index; RBA, Route-By-Area. Data are n and %, unless otherwise noted. There are missing data in: Perceived stress (13; 1.65%), Total PA (5; 0.63%), Country of birth (1; 0.13%), Living with family/partner (1; 0.13%), Employed people in household (4; 0.51), Children in household (2; 0.25%), Children <3years old in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂ (20; 2.54%). ^aChi square test, except for Age, Total PA, MVPA, VPA, and all the Environmental determinants (U Mann Whitney test).

Table S4. Sensitivity analyses exploring the relationships between perceived stress

(P75, P90) and all covariates.

Variable		Perceived stress	s (P75)	Perceived stress (P90)					
Vallauk	RI	R (95% CI)	p-value	RI	R (95% CI)	p-valu			
Individual determinants									
Age	1.00	(0.99, 1.02)	0.793	1.00	(0.97, 1.02)	0.662			
Total PA - min/week	1.00	(0.99, 1.00)	0.113	1.00	(0.99, 1.00)	0.802			
MVPA - min/week	1.00	(0.99, 1.00)	0.197	1.00	(0.99, 1.00)	0.701			
VPA - min/week	1.00	(0.99, 1.00)	0.382	1.00	(0.99, 1.00)	0.743			
Gender (Woman)	1.41	(1.03, 1.93)	0.032	1.69	(1.04, 2.76)	0.035			
Country of birth (non-Spanish)	1.16	(0.75, 1.78)	0.515	1.14	(0.58, 2.24)	0.695			
Working status (Student)	1.46	(0.99, 2.14)	0.051	1.04	(0.53, 2.04)	0.904			
Education level (University studies completed or equivalent-level education)	0.78	(0.57, 1.07)	0.119	0.80	(0.49, 1.30)	0.369			
Living with family/partner	1.00	(0.68, 1.47)	0.987	0.94	(0.53, 1.68)	0.841			
Employed people in household (2-5) MEDEA index	0.67	(0.50, 0.91)	0.011	0.75	(0.47, 1.20)	0.231			
1st tertile (least deprived)	1.00			1.00					
2nd tertile	1.42	(0.96, 2.11)	0.081	1.85	(0.99, 3.46)	0.054			
3rd tertile (most deprived)	1.45	(0.97, 2.14)	0.067	1.77	(0.94, 3.33)	0.076			
Children in household (Yes)	1.05	(0.76, 1.44)	0.778	0.92	(0.56, 1.51)	0.743			
Children <3 years in household (Yes)	0.61	(0.30, 1.25)	0.180	0.54	(0.17, 1.68)	0.289			
Self-perceived health (Very good/Excellent)	0.65	(0.47, 0.91)	0.011	0.88	(0.55, 1.42)	0.604			
BMI (Overweight/Obese)	1.08	(0.77, 1.51)	0.664	1.03	(0.61, 1.73)	0.92			
Chronic disease (Ves)	1.58	(1.01, 2.48)	0.047	1.65	(0.83, 3.32)	0.150			
Stress releasing (Agreement)	0.85	(0.57, 1.27)	0.423	0.94	(0.49, 1.79)	0.850			
Bicycle trin enjoyment (Agreement)	0.74	(0.52, 1.04)	0.085	0.79	(0.46, 1.37)	0.409			
beyere trip enjoyment (Agreement)					(0110, 001)				
Environmental determinants									
Commute distance, estimated (km)	1.07	(0.99, 1.14)	0.053	1.03	(0.92, 1.15)	0.620			
Public bicycle stations									
Home, count in 400m buffer	0.99	(0.93, 1.06)	0.770	0.94	(0.84, 1.04)	0.253			
Work/study, count in 400m buffer	0.96	(0.91, 1.01)	0.103	0.96	(0.89, 1.03)	0.242			
Greenness. NDVI									
Home, average of 400m buffer	0.95	(0.79, 1.14)	0.557	1.04	(0.81, 1.33)	0.768			
Work/study, average of 400m buffer	1.09	(0.94, 1.27)	0.262	0.99	(0.74, 1.32)	0.930			
Commute route, average of RBA	1.04	(0.88, 1.22)	0.655	1.18	(0.95, 1.47)	0.138			
NO ₂ pph		(,							
Home concentration in 400m buffer	1.00	(0.99, 1.00)	0.390	1.00	(0.98, 1.01)	0.728			
Work/study_concentration in 400m buffer	0.99	(0.99, 1.00)	0.042	0.99	(0.98, 1.00)	0.076			
Commute route, concentration in RBA	1.00	(0.99, 1.01)	0.474	0.99	(0.97, 1.00)	0.138			
Noise >55dB		()			()				
Home proportion in 400m buffer	1.01	(0.99, 1.02)	0.483	1.00	(0.98, 1.03)	0.84			
Work/study proportion in 400m buffer	1.00	(0.99, 1.01)	0.549	1.00	(0.98, 1.02)	0.835			
Commute route, proportion in RBA	1.00	(0.98, 1.01)	0.854	1.01	(0.98, 1.04)	0.444			
Rikeshility	1.00	()	0.02	1.01	(1.00, 1.01)	0.144			
Home concentration in 400m buffer	0.97	(0.87, 1.08)	0.532	0.92	(0.78, 1.09)	0.356			
Work/study, concentration in 400m buffer	0.97	(0.87, 1.00)	0.108	0.89	(0.75, 1.07)	0.216			
work study, concentration in 400m burler	0.92	(0.02, 1.02)	0.100	0.09	(0.66,0.00)	0.041			

 Commute route, concentration in RBA
 0.88
 (0.77, 1.00)
 0.055
 0.81
 (0.66, 0.99)
 0.042

 PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; MEDEA, Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómicas y Ambientales, in Spanish (Environmental and socioEconomic Inequalities in Mortality in small Spanish areas, translated to English); BMI, Body Mass Index; NDVI, Normalized Difference Vegetation Index; RBA, Route-By-Area. Complete case analysis excluding missing data of the variables of final models (Table S5; n=771). The variables that still present missing data and are not included in the final models are: Total PA (5; 0.63%), People living with in household (1; 0.13%), Children in household (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂(20; 2.54%).

Table S5. Sensitivity analyses exploring the relationships between bicycle commuting (Bicycle commuting status, Bicycle commuting

levels, Bicycle commuting propensity) and perceived stress (P75, P90).

7																									
8	Variable	RPI	Unadjusted		pp	Adjusted ^a	Perceived	stress (P75) Adjusted ^b		RB	Adjusted ^c		RB	Unadjusted		RP	Adjusted ^a	Perceived str	ess (P90)	Adjusted ^b		RB	Adjusted ^c	
a .		KK (9	95% CI)	p-value	кк (9	5% CI)	p-value	кк (9	Aujusieu 95% CI)	p-value	(9	5% CI)	p-value	лК (95% CI)	p-value	кк (9	5% CI)	p-value	(9	5% CI)	p-value	(9	5% CI)	p-value
20	All sample (771)																								
10	Bicycle commuting status																								
11	Non-bicycle commuters	1.00	(0.42.0.70)	0.001	1.00	(0.40.0.70)	0.001	1.00	(0.44.0.95)	0.004	1.00	(0.46.0.00)	0.011	1.00	(0.22, 0.90)	0.014	1.00	(0.24, 0.02)	0.025	1.00	(0.21, 0.89)	0.014	1.00	(0.22, 0.05)	0.022
12	Bicycle commuters	0.58	(0.42, 0.79)	0.001	0.58	(0.42, 0.79)	0.001	0.61	(0.44, 0.85)	0.004	0.64	(0.46, 0.90)	0.011	0.54	(0.33, 0.89)	0.014	0.56	(0.54, 0.95)	0.025	0.52	(0.51, 0.88)	0.014	0.56	(0.33, 0.95)	0.032
12	Non-bicycle commuters (0 days)	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
13	Low bicycle commuting (1-3 days)	1.04	(0.71, 1.54)	0.832	1.03	(0.70, 1.53)	0.868	1.08	(0.73, 1.59)	0.708	1.10	(0.74, 1.64)	0.626	1.20	(0.68, 2.11)	0.535	1.22	(0.68, 2.21)	0.505	1.14	(0.63, 2.07)	0.662	1.18	(0.65, 2.14)	0.589
14	Medium bicycle commuting (4 days)	0.22	(0.07, 0.66)	0.007	0.20	(0.07, 0.62)	0.005	0.21	(0.07, 0.65)	0.007	0.22	(0.07, 0.68)	0.009	0.15	(0.02, 1.05)	0.056	0.14	(0.02, 1.00)	0.050	0.14	(0.02, 0.95)	0.044	0.15	(0.02, 1.04)	0.054
15	High bicycle commuting (>=5 days)	0.45	(0.29, 0.70)	< 0.001	0.46	(0.30, 0.72)	0.001	0.50	(0.32, 0.78)	0.003	0.52	(0.33, 0.82)	0.005	0.34	(0.16, 0.70)	0.004	0.36	(0.17, 0.75)	0.006	0.33	(0.15, 0.69)	0.004	0.35	(0.17, 0.73)	0.005
16	Bicycle commuting propensity																								
10	Unwilling Non-bicycle commuters	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
17	Willing Non-bicycle commuters	0.71	(0.47, 1.06)	0.090	0.74	(0.49, 1.10)	0.135	0.71	(0.48, 1.06)	0.095	0.72	(0.48, 1.08)	0.116	0.66	(0.35, 1.22)	0.183	0.70	(0.38, 1.30)	0.255	0.70	(0.37, 1.30)	0.253	0.71	(0.38, 1.35)	0.298
18	Infrequent Bicycle commuters	0.92	(0.01, 1.58)	<0.001	0.92	(0.01, 1.39)	<0.095	0.94	(0.65, 1.45)	0.788	0.97	(0.04, 1.48)	<0.001	0.25	(0.12, 0.52)	<0.926	0.27	(0.57, 2.01)	<0.001	0.25	(0.55, 1.88)	<0.001	0.27	(0.13, 0.56)	<0.001
10	Frequent Bicycle commuters	0.55	(0.23, 0.34)	<0.001	0.50	(0.23, 0.33)	<0.001	0.58	(0.24, 0.39)	<0.001	0.40	(0.25, 0.02)	<0.001	0.25	(0.12, 0.32)	<0.001	0.27	(0.15, 0.50)	<0.001	0.25	(0.12, 0.52)	<0.001	0.27	(0.15, 0.50)	<0.001
19	Bicycle commuting levels																								
20	Low bicycle commuting (1-3 days)	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
21	Medium bicycle commuting (4 days)	0.21	(0.06, 0.66)	0.008	0.19	(0.06, 0.61)	0.005	0.19	(0.06, 0.60)	0.005	0.19	(0.06, 0.60)	0.004	0.12	(0.02, 0.92)	0.041	0.11	(0.02, 0.83)	0.032	0.11	(0.02, 0.80)	0.028	0.11	(0.02, 0.76)	0.026
22	High bicycle commuting (>=5 days)	0.43	(0.26, 0.73)	0.002	0.44	(0.26, 0.75)	0.002	0.44	(0.26, 0.75)	0.002	0.44	(0.26, 0.73)	0.002	0.28	(0.12, 0.65)	0.003	0.28	(0.12, 0.65)	0.003	0.27	(0.12, 0.64)	0.003	0.27	(0.12, 0.60)	0.001
22	Bicycle commuters propensity																								
25	Infrequent (1-3 days)	0.28	(0.23, 0.64)	<0.001	0.28	(0.22, 0.62)	<0.001	0.38	(0.22, 0.62)	<0.001	0.38	(0.22, 0.62)	<0.001	0.25	(0.11, 0.55)	0.001	0.24	(0.11.0.55)	0.001	0.24	(0.10.0.54)	0.001	0.22	(0.11.0.51)	<0.001
24	Frequent (>=4 days)	(394)	(0.23, 0.04)	<0.001	0.58	(0.23, 0.03)	<0.001	0.58	(0.23, 0.03)	<0.001	0.58	(0.23, 0.02)	<0.001	0.25	(0.11, 0.55)	0.001	0.24	(0.11, 0.55)	0.001	0.24	(0.10, 0.54)	0.001	0.23	(0.11, 0.51)	<0.001
25	Exposure Non-bicycle commuters sample	(304)																							
26	Unwilling	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
27	Willing	0.71	(0.47, 1.06)	0.090	0.72	(0.48, 1.07)	0.106	0.67	(0.45, 1.00)	0.051	0.69	(0.46, 1.03)	0.068	0.66	(0.35, 1.22)	0.183	0.68	(0.36, 1.26)	0.222	0.68	(0.36, 1.26)	0.221	0.71	(0.37, 1.36)	0.300
27	^a Adjusted by Gen	der, Cou	ntry of birth, E	mployed pe	ople in h	ousehold, Chr	onic diseas	e. ^b Adjus	ted by Age, Ge	nder, Count	ry of birt	h, Employed	people in hou	sehold, Cl	hronic disease,	Self-perceiv	ved healt	h, Moderate-to	o-Vigorous	Physical	Activity (MV	PA). °Adj	usted by		
28	Age, Gender, Cou	intry of b	oirth, Employed	i people in l	nousehol	d, Chronic dis	ease, Self-p	erceived	health, MVPA	, Public bicy	ycle statio	ons at work/st	udy, Bikeabili	ty at worl	k/study, Bikeat	ulity at com	mute rou	ite.							
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STROBE Statement-checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Reported in page
Title and abstract	1	(<i>a</i>) Indicate the study's design with a commonly used term in the title or the abstract	Page 2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2
Introduction			
Background/rati onale	2	Explain the scientific background and rationale for the investigation being reported	Pages 4, 5
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5
Methods			
Study design	4	Present key elements of study design early in the paper	Page 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Pages 6, 7
Participants	6	 (a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants 	Pages 6, 7
		(b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed Case-control study—For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Pages 7, 8, 9, 10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Pages 7, 8, 9, 10
Bias	9	Describe any efforts to address potential sources of bias	Pages 6, 7
Study size	10	Explain how the study size was arrived at	Pages 6, 7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Pages 7, 8, 9, 10
Statistical methods	12	(<i>a</i>) Describe all statistical methods, including those used to control for confounding	Page 10
		(b) Describe any methods used to examine subgroups and interactions	Page 10
		(c) Explain how missing data were addressed	Page 10
		(d) Cohort study—If applicable, explain how loss to follow-up was addressed Case-control study—If applicable, explain how matching of cases and controls was addressed Cross-sectional study—If applicable, describe analytical methods taking account of campling strategy	Page 10
Continued on next page	e	(<u>e</u>) Describe any sensitivity analyses	Pages 7, 8, 10

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Results			Reported in page
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 6
		(b) Give reasons for non-participation at each stage	Page 6
		(c) Consider use of a flow diagram	In previous papers
Descriptive	14*	(a) Give characteristics of study participants (eg demographic, clinical,	Pages 10, 11,
data		social) and information on exposures and potential confounders	12, 13, 14
		(b) Indicate number of participants with missing data for each variable of interest	Pages 6, 13, 14
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	-
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	-
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	-
		Cross-sectional study—Report numbers of outcome events or summary	Pages 10, 11,
		measures	12, 13, 14
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted	Pages 15, 16,
		estimates and their precision (eg, 95% confidence interval). Make clear	17
		which confounders were adjusted for and why they were included	
		(b) Report category boundaries when continuous variables were categorized	Pages 7, 8
		(<i>c</i>) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Pages 3, 4, 5 of Supplementar
			material
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 20
Interpretation	20	Give a cautious overall interpretation of results considering objectives,	Pages 18, 19,
		limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	20, 21
Generalisability	21	Discuss the generalisability (external validity) of the study results	Pages 20
Other informatio	on		
Funding	22	Give the source of funding and the role of the funders for the present study	Page 22
		and if applicable for the original study on which the present article is based	

unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The relationship between bicycle commuting and perceived stress: a cross-sectional study

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4 5	1	THE RELATIONSHIP BETWEEN BICYCLE COMMUTING
6 7	2	AND PERCEIVED STRESS: A CROSS-SECTIONAL STUDY
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53 54	23	Keywords: Bicycling, Commuting, Physical activity, Stress, Survey
55 56 57 58 59 60	24	Word count of main text: 4243

1 ABSTRACT

2	Introduction: Active commuting -walking and bicycling for travel to and/or from work or
3	educational addresses- may facilitate daily, routine physical activity. Several studies have
4	investigated the relationship between active commuting and commuting stress; however, there
5	are no studies examining the relationship between solely bicycle commuting and perceived
6	stress, or studies that account for environmental determinants of bicycling commuting and
7	stress. The current study evaluated the relationship between bicycle commuting, among
8	working or studying adults in a dense urban setting, and perceived stress.
9	Methods: A cross-sectional study was performed with 788 adults who regularly travelled to
10	work or study locations (excluding those who only commuted on foot) in Barcelona, Spain.
11	Participants responded to a comprehensive telephone survey concerning their travel behaviour
12	from June 2011 through to May 2012. Participants were categorised as either bicycle
13	commuters or non-bicycle commuters, and (based on the Perceived Stress Scale, PSS-4) as
14	either stressed or non-stressed. Multivariate Poisson regression with robust variance models
15	of stress status based on exposures with bicycle commuting were estimated, and adjusted for
16	potential confounders. Results: Bicycle commuters had significantly lower risk of being
17	stressed than non-bicycle commuters [RR (95%CI) = 0.73 (0.60, 0.89), p-value=0.001].
18	Bicycle commuters who bicycled four days per week [RR $(95\%$ CI) = 0.42 (0.24, 0.73), p-
19	value=0.002] and those who bicycled five or more days per week [RR $(95\%$ CI) = 0.57 (0.42,
20	0.77), p-value<0.001] had lower risk of being stressed than those who bicycled less than four
21	days. This relationship remained statistically significant after adjusting for individual and
22	environmental confounders, and when using different cut-offs of perceived stress.
23	Conclusions: Stress reduction may be an important consequence of routine bicycle use and
24	should be considered by decision makers as another potential benefit of its promotion.
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population density.

direction of causation.

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The study had high internal validity, with a good representation of bicycle commuters.

The study was conducted in Barcelona (a dense, Mediterranean/Southern European

city), adding evidence on these issues in a different context than the current literature.

The TAPAS Travel Survey sample is representative of Barcelona's population, taking

into account home-neighbourhood deprivation, and home and work-neighbourhood

Using questionnaire data, we could have misclassification error (information bias) of

The study used a cross-sectional design, which is not well-suited to assess the

bicycle commuting and physical activity due to the data being self-reported.

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STRENGHTS AND LIMITATIONS OF THIS STUDY

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1 INTRODUCTION

Walking and bicycling for transport is increasingly being promoted due to its potential for increasing physical activity (PA) levels in the general population (1-3). Active commuting – walking and bicycling for travel to and/or from work or educational addresses - has been associated with multiple health benefits from reductions of cardiovascular risk (4,5), lowering of body weight (2,5), improvement of fitness, reduction of diabetes risk (3), and increasing levels of physical and mental well-being (6,7). Specifically, bicycle commuting has been inversely associated with all-cause mortality among both men and women in all age groups (8) and it seems likely to improve the health-related quality of life in previously-untrained healthy adults (9). Active commuting has been shown to have other societal benefits such as helping reduce air pollution, greenhouse gas emissions, and noise, and improving social interaction (10).

Perceived stress is a global and comprehensive stress construct that refers to the interaction between the individual and the environment in the presence of a stressor (11). The perception of an event as being stressful can result in a range of physiological, behavioural, and psychological changes, and can lead to cardiovascular disease, increased negative affect, lowered self-esteem, and lowered feelings of control. Hence, it is possible that mental health outcomes such as anxiety disorders and depression can be manifestations of chronic, perceived stress (12). Furthermore, others have suggested gender differences in stress-related variables. Women seem to be more likely to have daily stress, being more physiologically reactive to social rejection challenges (13), and be more impacted by life events (14).

24 Some literature recognises commuting as a potential source of stress (15); however, active

25 commuters have been shown to have higher levels of satisfaction, lower stress, higher
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1	relaxation and a heightened sense of freedom compared to car drivers (16-18). Recent
2	qualitative research has suggested that commuting can be perceived as a relaxing or
3	transitional time between home and work life, which can also be about enjoying pleasant
4	landscape, nature and wildlife (19). Emerging literature has highlighted the relevance of a
5	positive natural and built environment to increase bicycle commuting and to improve mental
6	health outcomes. Bicycle lane connectivity, bikeability, separation of bicycling from other
7	traffic, high population density, short trip distance, proximity of a cycle path, green space and
8	also walkability have been suggested as determinants of bicycling (20-24). Green space has
9	also been associated with better self-perceived general health and better mental health (25,26).
10	
11	Several studies have examined the relationship between active commuting and commuting
12	stress (stress directly related with the act of commuting) (17,18,27,28), but none of them have
13	studied the relationship between solely bicycle commuting and perceived stress (global and
14	comprehensive stress construct) in adults, nor taking into account environmental
15	determinants. Moreover, most studies of active commuting and its beneficial effects on
16	mental health have been conducted in North America, where the urban design tends to be less
17	dense than many parts of the world, or Northwest Europe (6,7,17,28–30). Consequently, a
18	need exists to understand the relationship between bicycle commuting and perceived stress,
19	particularly in dense, Mediterranean/Southern European urban environments.
20	
21	The current study aimed to evaluate the relationship between bicycle commuting and
22	perceived stress among the working or studying adult population of a dense,
23	Mediterranean/Southern European urban setting.
24	

1 MATERIALS AND METHODS

2 Study population

This cross-sectional study was based on participants from the Transportation, Air Pollution and Physical ActivitieS (TAPAS) Travel Survey. TAPAS is a relatively large study aimed at investigating the risks and benefits of active commuting. Participant recruitment was conducted by trained interviewers on the streets of Barcelona city between June 2011 and May 2012. To ensure adequate geographic coverage, a total of 40 random points (four random points within each of the ten city districts across Barcelona) were sampled. Adult bicycle commuters and non-bicycle commuters were asked in the street to answer a few screening questions, and those who fulfilled the inclusion criteria (being older than 18 years of age; living in Barcelona city since 2006 or earlier; working or going to school in Barcelona city; being healthy enough to ride a bicycle for 20 minutes; having a commute distance greater than a 10-minute walk; and using at least one mode of transport other than walking to commute) were invited to respond to a telephone survey. Bicycle commuters were oversampled to ensure enough bicycle commuters in the study. Those solely commuting on foot were excluded as the main interest was in the contrast between motorized modes (private and public transportation) and the bicycle. Of the 18469 participants approached across the forty sampling random points, 6701 agreed to answer screening questions. Of these, 1508 met the inclusion criteria, and 871 participants completed the survey. After survey responses were checked by the research team, 815 still fulfilled the inclusion criteria and 789 had geocodable home address. After excluding one PA outlier (total of all walking, moderate and vigorous time variables >960 minutes/day), 788 participants remained. Further details on the recruitment is given elsewhere (31).

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1	The study protocol was approved by the Clinical Research Ethical Committee of the Parc de
2	Salut Mar (CEIC-Parc de Salut Mar), and written informed consent was obtained from all
3	participants.
4	
5	Bicycle commuting
6	The TAPAS Travel Survey assessed the regular use of transport modes (32), including
7	bicycles (33). Participants who indicated using a bicycle (private or from a public bicycle
8	sharing system) to go to work or school at least once the week prior to survey administration
9	were classified as "bicycle commuters". Participants who did not commute by bicycle in the
10	week prior to survey administration were classified as "non-bicycle commuters".
11	
12	As part of the sensitivity analyses, commuting behaviour was further classified according to
13	bicycle commuting levels and bicycle commuting propensity (24). Classification of bicycle
14	commuting levels was based on the days of bicycle commuting in the week prior to survey
15	administration: "low-level" being three days or fewer, "medium-level" for four days, and
16	"high-level" for five or more days. This measure could be interpreted as a proxy of bicycle
17	commuting frequency. Bicycle commuting propensity classification took into account both
18	frequency and willingness to commute by bicycle: the "bicycle commuters" were further
19	classified as "frequent" (four or more days) or "infrequent" (three or less days), and the "non-
20	bicycle commuters" were classified as "willing" or "unwilling". The "willing" group were
21	those "non-bicycle commuters" who indicated bicycling as "never or nearly never" their
22	general transport mode, but who also indicated that they would consider bicycle commuting
23	in Barcelona (by answering positively to "considering costs, travelling time, comfort and
24	safety, how ready would you be to use the bicycle/Bicing (public bicycle-sharing system) for
25	your trip to work or education centre?"). The "unwilling" group were those "non-bicycle

commuters" who indicated "never or nearly never" bicycling for travel and indicated that they
 would not consider bicycle commuting in Barcelona by answering negatively to the above
 question. More details of the bicycle commuting propensity classification are given elsewhere
 (24). This measure was included in the analysis to assess the effect on perceived stress by
 being willing to commute by bicycle.

Perceived stress

The last four questions of the TAPAS Travel Survey were the short version of the Perceived Stress Scale (PSS-4) (11), which is a well-validated psychological instrument to measure the degree to which situations in one's life over the past month are appraised as stressful. The instrument contains four statements, which measure how unpredictable, uncontrollable, and overloaded respondents feel that their lives are (Table S1). The higher the score on the PSS-4 (from 0 to 16), the greater the respondent perceives that their demands exceed their ability to cope. There are no cut-off scores. Instead, an individual's score is compared to a normative value (34). In the TAPAS Travel Survey the 5-point Likert scale was modified to a 4-point Likert scale, removing the midpoint option for consistency with other questions in the survey (using a 4-point Likert scale). The sample did not have high levels of perceived stress (Table S2); therefore, for an easier interpretation, participants with a PSS-4 score higher than 3 (median of the total sample) were classified as "stressed", and those equal or lower than 3 were classified as "non-stressed". The sensitivity of our results to this choice was examined further in sensitivity analyses by classifying the respondents with PSS-4 scores in the 75th percentile (P75) and above (a score higher than 4) and in the 90th percentile (P90) and above (a score of 6 and above) as stressed and all others as non-stressed.

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1 Other explanatory measures

Individual determinants of bicycle commuting and perceived stress such as physical activity levels (35), socio-demographic variables, and work or school addresses were also derived from the TAPAS Travel Survey to be used as potential confounders. In addition, the MEDEA Index (Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómicas y Ambientales, in Spanish; Environmental and socioEconomic Inequalities in Mortality in small Spanish areas, translated to English) was used as an area deprivation indicator assigned to each participants' address. MEDEA measures deprivation at the census tract level based on five domains including percentage of manual workers, temporary workers, total population with low education, young population with low education, and unemployment (36). Environmental determinants of bicycle commuting and perceived stress within a 400m buffer surrounding home and work/study addresses, and a Route-By-Area (RBA) surrounding predicted commute routes, were calculated to be used as potential confounders too. The number of public bicycle stations within a 400m buffer surrounding home and work/study addresses was calculated based on information from the Ajuntament de Barcelona -Informació de Base i Cartografia (IBC) (Barcelona City Council – Basic information and mapping). Greenness was calculated as a mean in Normalized Difference Vegetation Index (NDVI) via satellite imagery (LANDSAT 4 and 5, NASA). Mean NO₂ levels were estimated

20 using a land-use regression model developed for a previous project (37). Noise was calculated

as the proportion of street length above a 55 dB(A) threshold (38). A bikeability index was

22 calculated taking into account five factors shown to influence bicycling: bicycle facility

availability, bicycle facility quality, street connectivity, topography, and land use (39).

24 Commute distance did not use buffers and it was calculated in km following the street

1	network of the shortest route from home address to work address. Further details of the
2	environmental determinants calculation are given elsewhere (24).

Statistical analyses

Descriptive univariate analyses were done for all study variables. Descriptive bivariate analyses were done using Chi square and U Mann Whitney tests to assess the relationship between determinants and bicycle commuting variables (bicycle commuting status, bicycle commuting levels, and bicycle commuting propensity); and using Poisson regression with robust variance models to assess the relationship between determinants and perceived stress. A Generalized Additive Model (GAM) was used to test linearity between perceived stress and total physical activity (Total PA), moderate-to-vigorous physical activity (MVPA), vigorous physical activity (VPA), and age (40). As there was no statistical evidence to reject linearity between perceived stress and Total PA (p-value = 0.382), MVPA (p-value = 0.503), VPA (p-val value = 0.163), and age (p-value = 0.228), these variables were included as continuous variables in the models assuming a linear relationship. Multivariate Poisson regression with robust variance models were used to assess the relationship between bicycle commuting and perceived stress. Four regression models were done: (1) unadjusted; (2) adjusted by individual determinants that showed a p-value <0.05 in the model; (3) adjusted by the individual determinants of model 2, as well as those found to be statistically significant within previous literature; (4) adjusted by the individual determinants of model 3 and environmental determinants that showed a p-value < 0.05 in the bivariate analyses. All multivariate regression models were conducted with a complete case analysis. Possible mediation by different levels of PA between bicycle commuting and perceived stress, and any interaction between gender and bicycle commuting were also tested with Poisson regression with robust variance models. The first descriptive statistical analyses (univariate, Chi square and U Mann

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1	Whitney tests) were conducted in Stata version SE 12 (StataCorp LP, Texas USA), while
2	Poisson regression with robust variance models were conducted in Stata version SE 14
3	(StataCorp LP, Texas USA).

RESULTS

The included sample had an equal distribution of genders and the median age (P25-P75) was 36 (29-43) years (Table 1). The majority of participants were non-stressed (having a PSS-4 score of 3 or lower), were Spanish, had completed university studies or equivalent-level education, were living with their family or partner, with at least two employed people, and were not with children (64.34%). Among those living with children, ~8% had children younger than three years of age. The sample had positive self-perception of health (with only <1% of participants self-perceiving bad or very bad health), healthy weight (BMI of 18.5-24.9: 71.12%), and generally no chronic disease (92.26%). The majority of participants considered that they could release stress when riding a bicycle and that they enjoyed their trip more if they used a bicycle. Compared to non-bicycle commuters, bicycle commuters were statistically significantly (p-value<0.05) more likely to be: non-stressed; younger (35 years); men; have higher levels of PA; possess a university or equivalent-level education; live alone and/or with flat mates; live with one or less employed people; live with no children; and have better self-perception of health, and healthy weight, but more chronic diseases. Bicycle commuters had shorter commutes compared to non-bicycle commuters, and we observed a gradient between commute distance and bicycle commuting levels; shorter distances were travelled for those who bicycle commuted more frequently. This tendency was also seen with bicycle commuting propensity; shorter distances were travelled for those more willing to bicycle commute (Table S3). Bicycle commuters also had more public bicycle stations around the home and work/study addresses, lower average greenness around the home address, and higher levels of bikeability at home, work/study address, and on the commute route compared

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1	to non-bicycle commuters (Table 1). These environmental determinants stayed statistically
2	significant for bicycle commuting propensity, but not between bicycle commuting levels
3	(Table S3).

Participants more likely to be stressed (p-value<0.05) were typically women, non-Spanish, living with one or less people employed, and had a chronic disease (Table 2). For environmental determinants, participants who had more public bicycle stations around their work/study area and higher levels of bikeability in the work/study address area as well as on the commute route were less likely to be stressed (p < 0.05). There was no statistically significant relationship between commute distance, greenness, NO₂ and noise, and perceived stress. The possible mediation of PA was not further explored as there was no statistically significant relationship between levels of PA (Total PA, MVPA and VPA) and perceived stress for the three different classifications of perceived stress (P50, P75, P90) [RR (95% CI): 1.00 (0.99, 1.00), all p-values>0.10] (Table 2, Table S4).

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1 Table 1. Descriptive analyses of participant perceived stress and its determinants as a total

2 sample and according to bicycle commuting status.

	Total	sample (799)					
Variables	1018	sample (700)	Non-bicycle	commuters (390)	Bicycle co	n-value ^a	
	n	%	n	%	N	%	p (ulue
Outcome							
Stressed (median) (Yes)	280	35.53	162	41.97	118	30.33	0.001
Individual determinants							
Age (median; P25-P75)	36	29-43	37	30-45	35	29-41	0.025
Total PA – min/week (median; P25-P75)	424.99	269.99-700.00	374.99	209.99-624.99	484.98	329.99-734.99	< 0.001
MVPA – min/week (median; P25-P75)	197.49	72.50-374.99	90.00	0-40	299.99	159.99-464.99	< 0.001
VPA – min/week (median; P25-P75)	/2.50	0-180.00	35.00	0-134.99	105.00	0-225.00	< 0.001
Gender (Woman)	410	52.03	234	60.00	1/6	44.22	< 0.001
Country of birth (non-Spanish)	97	12.31	41	10.51	50	14.11	0.125
Education level (University studies completed or equivalent-level education)	104 551	13.20 69.92	247	63.33	304	76.38	<0.001
Living with family/partner	635	80.58	327	83.85	308	77.58	0.026
Employed people in household (2-5)	510	64.72	261	67.27	249	62.88	0.198
MEDEA index							0.355
1st tertile (least deprived)	263	33.38	130	33.33	133	33.42	
2nd tertile	263	33.38	122	31.28	141	35.43	
3rd tertile (most deprived)	262	33.25	138	35.38	124	31.16	
Children in household (Yes)	279	35.41	151	38.82	128	32.24	0.054
Children <3 years in household (Yes)	64	8.12	36	9.25	28	7.07	0.264
Self-perceived health (Very good/Excellent)	323	40.99	140	35.90	183	45.98	0.004
BMI (Overweight/Obese)	212	26.9	124	31.96	88	22.11	0.002
Chronic disease (Yes)	61	7.74	25	0.41 70.47	30	9.05	0.166
Stress releasing (Agreement)	620	83.30	302	/9.4/ 65.25	330	90.39	< 0.001
Bicycle trip enjoyment (Agreement)	029	19.82	249	05.55	380	90.20	<0.001
Environmental determinants	2.05		4.00	2.25	2.25	1.70	-0.001
Commute distance, estimated (km) (mean;SD)	3.85	2.05	4.38	2.25	3.35	1.70	< 0.001
Public bicycle stations (mean;SD)							
Home, count in 400m buffer	4.25	2.54	3.75	2.51	4.75	2.47	< 0.001
Work/study, count in 400m buffer	4.92	3.11	4.50	3.13	5.33	3.04	< 0.001
Greenness, NDVI [IQR, (mean;SD)]							
Home, average of 400m buffer	0.79	1.07	0.91	1.08	0.68	1.06	< 0.001
Work/study, average of 400m buffer	0.62	0.96	0.70	1.07	0.55	0.83	0.086
Commute route average of RBA	0.97	0.96	1.07	1.06	0.87	0.85	0.062
NO_2 ppb (mean;SD)							
Home, concentration in 400m buffer	76.20	17.52	75.16	17.12	77.21	17.87	0.058
Work/study_concentration in 400m buffer	78.43	22.51	78.56	23.92	78.31	21.10	0.843
Commute route concentration in RBA	84.40	16.97	84.24	16.82	84.55	17.13	0.987
Noise >55dB (%) (mean:SD)							
Home properties in 400m buffer	78.63	11 40	78 77	10.99	78 50	11 79	0.823
Wark (study, gran action in 400m buffer	79 59	14 66	79.09	14.86	80.07	14 46	0.369
work/study, proportion in 400m butter	77 40	0.04	77.07	9 50	77.20	0.40	0.009
Commute route, proportion in RBA	//.40	9.04	//.31	0.30	/7.50	9.48	0.924
Bikeability (mean;SD)							0.004
Home, concentration in 400m buffer	6.20	1.41	5.93	1.45	6.46	1.31	< 0.001
Work/study, concentration in 400m buffer	6.56	1.39	6.31	1.54	6.79	1.17	< 0.001
Commute route, concentration in RBA	6.70	1.12	6.45	1.20	6.94	0.98	< 0.001

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Table 2. Bivariate analyses of the relationship between participant determinants and

perceived stress.

Variable	Perceived stress (median)							
variable	RR (95% CI)	p-value						
Individual determinants								
	1.00 (0.00 1.01)	0.502						
Total DA min/week	$1.00 \ (0.99, 1.01)$ $1.00 \ (0.99, 1.00)$	0.502						
MVPA min/week	$1.00 \ (0.99, 1.00)$ $1.00 \ (0.99, 1.00)$	0.009						
VPA min/week	$1.00 \ (0.99, 1.00)$ $1.00 \ (0.99, 1.00)$	0.658						
Gender (Wemen)	$1.00 \ (0.99, 1.00)$ $1.55 \ (1.27, 1.80)$	<0.001						
Country of hirth (Spain)	1.33 (1.27, 1.69) 1.24 (1.05, 1.70)	<0.001						
Working status (Student)	1.34 (1.05, 1.70) 1.22 (0.05, 1.56)	0.017						
Education level (University studies completed	1.22 (0.95, 1.50)	0.115						
or Others)	0.02 (0.75 1.12)	0.387						
Living with family/partner	$0.92 (0.73, 1.12) \\ 0.01 (0.72, 1.15)$	0.430						
Enving with family/particle	0.91 (0.73, 1.13) 0.74 (0.62, 0.90)	0.439						
MEDEA index	0.74 (0.02, 0.90)	0.002						
Ist tertile (least deprived)	1.00							
2nd tertile	1.00	0.537						
2nd tentile (mont demnined)	1.08 (0.03, 1.37)	0.337						
Staterine (most deprived)	1.18 (0.94, 1.48)	0.162						
Children in nousenoid (Yes)	0.90 (0.74, 1.11)	0.550						
Children <3 years in nousenoid (Yes)	0.87 (0.60, 1.27)	0.475						
Self-perceived health (Very good/Excellent)	0.87 (0.71, 1.06)	0.157						
BMI (Overweight/Obese)	0.95 (0.77, 1.18)	0.669						
Chronic disease (Yes)	1.38 (1.04, 1.83)	0.024						
Stress releasing (Agreement)	0.87 (0.68, 1.11)	0.273						
Bicycle trip enjoyment (Agreement)	0.91 (0.72, 1.14)	0.425						
Environmental determinants								
Commute distance estimated (km)	1.02 (0.97 1.06)	0.508						
Public bicycle stations	1.02 (0.57, 1.00)	0.000						
Home count in 400m buffer	0.99 (0.95 1.02)	0.503						
Work/study_count in 400m buffer	0.96 (0.93, 0.99)	0.003						
Greenness NDVI	$(0.90 \ (0.95, 0.99)$	0.024						
Home average of 400m huffer	0.94 (0.85, 1.05)	0 258						
Work/study average of 400m buffer	1.06 (0.05, 1.05)	0.238						
Commute route, average of PBA	0.00 (0.80 1.00)	0.838						
NO pph	(0.39) $(0.39, 1.09)$	0.858						
Home concentration in 400m huffer	1.00 (0.00 1.01)	0.827						
Work/study, concentration in 400m buffer	1.00 (0.99, 1.01) 1.00 (0.00, 1.00)	0.027						
Commute route, concentration in PPA	1.00 (0.99, 1.00) 1.00 (0.00, 1.00)	0.100						
Noise >55dD	1.00 (0.99, 1.00)	0.516						
Home menories in 400m huffer	1.00 (0.00 1.00)	0.262						
Home, proportion in 400m buffer	1.00 (0.98, 1.00) 1.01 (0.00, 1.01)	0.303						
Commute neutron neutron in ADA	1.01 (0.99, 1.01)	0.125						
Dilanchility	1.00 (0.98, 1.01)	0.405						
Hama apparentiation in 400m huffer	1.00 (0.04 1.07)	0.021						
nome, concentration in 400m buffer	1.00 (0.94, 1.07)	0.931						
work/study, concentration in 400m buffer	0.92 (0.86, 0.98)	0.009						
Commute route, concentration in RBA	0.91 (0.84, 0.98)	0.018						

PA, Physical Activity; MPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; MEDEA, Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómicas y Ambientales, in Spanish (Environmental and socioEconomic Inequalities in Mortality in small Spanish areas, translated to English); BMI, Body Mass Index, NDVI, Normalized Difference Vegetation Index; RBA, Route-By-Area. Complete case analysis excluding missing data of the variables of final models (Table 3; n=771). The variables that still present missing data and are not included in the final models are: Total PA (5; 0.63%), People living with in household (1; 0.13%), Children in household (2; 0.25%), Children <3 per solution in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂ (20, 2.54%).

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1	Multivariate Poisson regression with robust variance analyses showed a statistically
2	significant inverse relationship between bicycle commuting and perceived stress. Considering
3	the total sample, bicycle commuters had a lower risk of being stressed compared to non-
4	bicycle commuters [Model 1: RR (95%CI) = 0.73 (0.60, 0.89), p-value=0.001]. This
5	relationship remained statistically significant in the adjusted models [Model 2: RR (95%CI) =
6	0.75 (0.62, 0.91), p-value=0.003; Model 3: RR (95%CI) = 0.77 (0.63, 0.94), p-value=0.009;
7	Model 4: RR (95%CI) = 0.80 (0.66, 0.99), p-value=0.036] (Table 3) and when using
8	perceived stress cut-offs of either P75 or P90 (Table S5). Regarding bicycle commuting levels
9	in the total sample, those who bicycle commuted four days per week (considered "medium-
10	level" of bicycle commuters) and those who bicycled five or more days per week ("high-
11	level") had lower risk of being stressed than non-bicycle commuters ["Medium-level" -
12	Model 1: RR (95%CI) = 0.46 (0.28, 0.78), p-value=0.004. "High-level" – Model 1: RR
13	(95%CI) = 0.63 (0.49, 0.81), p-value<0.001]. These relationships remained statistically
14	significant in the adjusted models ("Medium-level" - Model 2: RR (95%CI) = 0.45 (0.27,
15	0.74), p-value=0.002; Model 3: RR (95%CI) = 0.45 (0.27, 0.75), p-value=0.002; Model 4: RR
16	(95%CI) = 0.48 (0.29, 0.80), p-value=0.005. "High-level" - Model 2: RR (95%CI) = 0.66
17	(0.51, 0.85), p-value=0.001; Model 3: RR (95%CI) = 0.68 (0.52, 0.88), p-value=0.003; Model
18	4: RR (95%CI) = 0.71 (0.54, 0.92), p-value=0.010) (Table 3) and in the majority of perceived
19	stress sensitivity analyses (using cut-offs of P75 and P90), with the exception of the
20	unadjusted and fully adjusted models (Models 1 and 4) for "medium-level" bicycle
21	commuters using P90 as a perceived stress cut-off ["Medium-level" - Model 1: RR (95%CI) =
22	0.15 (0.02, 1.05), p-value=0.056; Model 4: RR (95%CI) = 0.15 (0.02, 1.04), p-value=0.054]
23	(Table S5). Regarding bicycle commuting propensity in the total sample, "frequent" bicycle
24	commuters had lower risk of being stressed than "unwilling" non-bicycle commuters [Model
25	1: RR (95%CI) = 0.53 (0.41, 0.67), p-value<0.001]. This relationship remained statistically

1	significant in the adjusted models [Model 2: RR (95%CI) = 0.55 (0.43, 0.70), p-value<0.001;
2	Model 3: RR (95%CI) = 0.56 (0.43, 0.72), p-value<0.001; Model 4: RR (95%CI) = 0.58
3	(0.45, 0.76), p-value<0.001] (Table 3) and when using perceived stress cut-offs of either P75
4	or P90 (Table S5). Also, "willing" non-bicycle commuters had lower risk of being stressed
5	than "unwilling" non-bicycle commuters [Model 1: RR (95%CI) = 0.72 (0.56, 0.94), p-
6	value=0.014]. This relationship remained statistically significant in the adjusted models
7	[Model 2: RR (95%CI) = 0.75 (0.58, 0.97), p-value=0.029; Model 3. RR (95%CI) = 0.74
8	(0.57, 0.96), p-value=0.022; Model 4: RR (95%CI) = 0.75 (0.58, 0.97), p-value=0.031] (Table
9	3), but not when using perceived stress cut-offs of either P75 or P90 (Table S5).
10	
11	When considering bicycle commuting levels within the bicycle commuters only sample,
12	"medium-level" and "high-level" bicycle commuters had lower risk of being stressed than
13	"low-level" bicycle commuters ["Medium-level" - Model 1: RR $(95\%$ CI) = 0.42 (0.24, 0.73),
14	p-value=0.002. "High-level" - Model 1: RR (95%CI) = 0.57 (0.42, 0.77), p-value<0.001].
15	These relationships remained statistically significant in the adjusted models (["Medium-level"
16	- Model 2: RR (95%CI) = 0.39 (0.23, 0.67), p-value=0.001; Model 3: RR (95%CI) = 0.39
17	(0.23, 0.65), p-value<0.001; Model 4: RR (95%CI) = 0.38 (0.23, 0.65), p-value<0.001.
18	"High-level" - Model 2: RR (95%CI) = 0.59 (0.44, 0.80), p-value=0.001; Model 3: RR
19	(95%CI) = 0.59 (0.44, 0.80), p-value=0.001; Model 4: RR (95%CI) = 0.59 (0.44, 0.80), p-
20	value=0.001) (Table 3) and when using perceived stress cut-offs of either P75 or P90 (Table
21	S5). Regarding bicycle commuting propensity, "frequent" bicycle commuters had lower risk
22	of being stressed than "infrequent" bicycle commuters [Model 1: RR $(95\%$ CI) = 0.54 (0.40,
23	0.72), p-value<0.001]. This relationship remained statistically significant in the adjusted
24	models [Model 2: RR (95%CI) = 0.55 (0.41, 0.73), p-value<0.001; Model 3: RR (95%CI) =

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	1	0.54 (0.41, 0.72), p-value<0.001; Model 4: RR (95%CI) = 0.54 (0.41, 0.72), p-value<0.001]
	2	(Table 3) and when using perceived stress cut-offs of either P75 or P90 (Table S5).
	3	
	4	Considering bicycle commuting propensity within the non-bicycle commuters only sample,
	5	"willing" non-bicycle commuters had lower risk of being stressed than "unwilling" non-
	6	bicycle commuters [Model 1: RR (95%CI) = 0.72 (0.56, 0.94), p-value=0.015]. This
	7	relationship remained statistically significant in the adjusted models [Model 2: RR (95%CI) =
	8	0.73 (0.57, 0.95), p-value=0.020; Model 3: RR (95%CI) = 0.72 (0.56, 0.93), p-value=0.013;
	9	Model 4: RR (95%CI) = 0.74 (0.57, 0.95), p-value=0.020] (Table 3), but not when using
	10	perceived stress cut-offs of either P75 or P90 (Table S5).
	11	
	12	In the fully adjusted models (Model 4), we found no statistically significant interactions
	13	between gender and being a bicycle commuter (p-value= 0.165), between gender and bicycle
	14	commuting levels (p-value=0.226, p-value=0.266, p-value=0.431), or between gender and
	15	bicycle commuting propensity (p-value=0.982, p-value=0.197, p-value=0.277) (results not
	16	shown).

Table 3. Multivariate models assessing the relationship between bicycle commuting and participant perceived stress (median).

	Perceived stress (median)											
Variable	Model 1 ^a RR (95% CI)		p-value	Model 2 ^b RR (95% CI)		p-value	Model 3 ^c RR (95% CI)		p-value	Model 4 ^d RR (95% CI)		p-value
All sample (771)		<u>`</u>			2			· · · · ·				
Bicycle commuting status												
Non-bicycle commuters	1.00			1.00			1.00			1.00		
Bicycle commuters	0.73	(0.60, 0.89)	0.001	0.75	(0.62, 0.91)	0.003	0.77	(0.63, 0.94)	0.009	0.80	(0.66, 0.99)	0.036
Bicycle commuting levels												
Non-bicycle commuters (0 days)	1.00			1.00			1.00			1.00		
Low-level bicycle commuters (1-3 days)	1.10	(0.87, 1.39)	0.436	1.11	(0.88, 1.40)	0.369	1.13	(0.89, 1.44)	0.297	1.17	(0.92, 1.48)	0.205
Medium-level bicycle commuters (4 days)	0.46	(0.28, 0.78)	0.004	0.45	(0.27, 0.74)	0.002	0.45	(0.27, 0.75)	0.002	0.48	(0.29, 0.80)	0.005
High-level bicycle commuters (>=5 days)	0.63	(0.49, 0.81)	< 0.001	0.66	(0.51, 0.85)	0.001	0.68	(0.52, 0.88)	0.003	0.71	(0.54, 0.92)	0.010
Bicycle commuting propensity												
Unwilling non-bicycle commuters	1.00			1.00			1.00			1.00		
Willing non-bicycle commuters	0.72	(0.56, 0.94)	0.014	0.75	(0.58, 0.97)	0.029	0.74	(0.57, 0.96)	0.022	0.75	(0.58, 0.97)	0.031
Infrequent bicycle commuters	0.98	(0.76, 1.25)	0.847	1.00	(0.78, 1.27)	0.980	1.01	(0.79, 1.30)	0.940	1.04	(0.81, 1.34)	0.739
Frequent bicycle commuters	0.53	(0.41, 0.67)	< 0.001	0.55	(0.43, 0.70)	< 0.001	0.56	(0.43, 0.72)	< 0.001	0.58	(0.45, 0.76)	< 0.001
Bicycle commuters sample (387)												
Bicycle commuting levels												
Low-level bicycle commuters (1-3 days)	1.00			1.00			1.00			1.00		
Medium-level bicycle commuters (4 days)	0.42	(0.24, 0.73)	0.002	0.39	(0.23, 0.67)	0.001	0.39	(0.23, 0.65)	< 0.001	0.38	(0.23, 0.65)	< 0.001
High-level bicycle commuters (>=5 days)	0.57	(0.42, 0.77)	< 0.001	0.59	(0.44, 0.80)	0.001	0.59	(0.44, 0.80)	0.001	0.59	(0.44, 0.80)	0.001
Bicycle commuters propensity												
Infrequent bicycle commuters	1.00			1.00			1.00			1.00		
Frequent bicycle commuters	0.54	(0.40, 0.72)	< 0.001	0.55	(0.41, 0.73)	< 0.001	0.54	(0.41, 0.72)	< 0.001	0.54	(0.41, 0.72)	< 0.001
Non-bicycle commuters sample (384)												
Bicycle commuters propensity												
Unwilling non-bicycle commuters	1.00			1.00			1.00			1.00		
Willing non-bicycle commuters	0.72	(0.56, 0.94)	0.015	0.73	(0.57, 0.95)	0.020	0.72	(0.56, 0.93)	0.013	0.74	(0.57, 0.95)	0.020

Willing non-bicycle commuters 0.72 (0.36, 0.44) 0.013 0.75 (0.57, 0.93) 0.020 0.72 (0.36, 0.93) 0.020 0.72 (0.36, 0.93) 0.020 0.75 0.14 (0.37, 0.93) 0.020
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DISCUSSION

2 Summary of results

We evaluated relationships between bicycle commuting and perceived stress while adjusting for several confounders in a representative sample of adults in Barcelona, Spain. We found statistically significant inverse relationships between several measures of bicycle commuting and perceived stress. Bicycle commuters who bicycled four or more days per week had lower risk of being stressed compared to those who bicycled less or did not bicycle commute at all. This relationship remained statistically significant in all sensitivity analyses and after controlling for individual and environmental confounders.

Comparison with previous studies

To our knowledge, this study is the first to assess whether a relationship exists between solely bicycle commuting and perceived stress. A few studies have focused on the relationship between active commuting (as a combination of both walking and bicycling) and mental health (6,7,29), but the relationship is still unclear. One study found a positive association of active commuting with well-being in adults (6), and another with better mental health in only men (29). Meanwhile, Humphreys and colleagues (7) found a positive relationship between time spent actively commuting and levels of physical well-being, but not with mental well-being. The relationship between physical activity and mental health has been studied more. It has been suggested that physical activity can reduce stress and anxiety on a daily basis while improving positive self-perception and mood (41–43), and it has been associated with lower depressive symptomatology and greater emotional well-being (44). These findings suggest that the physical activity gained during bicycle commuting (31) may act as a mediator in the relationship between bicycle commuting and perceived stress. Our results are consistent with

the general idea that active commuting is associated with better mental health, but in our case
physical activity did not act as a mediator in this relationship. Our sample was composed of
young, healthy, and active participants with relatively low PSS-4 levels of perceived stress,
which might have led to an underestimation of the relationship between PA and perceived
stress.

Qualitative research has suggested that choice of travel mode may affect well-being (19). The quantity of public bicycle (*Bicing*) stations and the amount of greenness has been related to bicycle commuting propensity (24), which could imply that commuting by bicycle provides people with more opportunities to "enjoy" or "experience" greenness than commuting in public transport or a car. At the same time, the availability of green space close to one's home has been shown to be related to better self-perceived general health and better mental health (25,26,45). Therefore, it seems that perceptual and environmental factors related to bicycle commuting could affect perceived stress, in the way that the more pleasant an environment to bicycle commuting is, the lower the perceived stress we will get. This general idea is consistent with our results which show an inverse relationship between perceived stress and bicycle-friendly environments (public bicycle stations and bikeability levels) in work/study address area and the commute route. Importantly, the relationship between bicycle commuting and perceived stress was unchanged after controlling for environmental confounders. Our results also showed that general attitude might have a role in this relationship, as we have seen that non-bicycle commuters willing to start bicycle commuting, compared to those unwilling, had lower risk of being stressed. This becomes unclear, however, as the relationship approaches statistical non-significance in sensitivity analyses.

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2	Limitations and strengths
3	Our study has some limitations. Firstly, our study used a cross-sectional design, which is not
4	well-suited to assess the direction of causation, and we cannot exclude reverse causality or
5	residual confounding. It has been suggested that stressed people can engage in unhealthy
6	behaviours, such as poor dietary practices or a lack of physical activity (46). This reasoning
7	could be applied to a behaviour like bicycle commuting, where those individuals who are
8	more stressed would bicycle less. Secondly, our measurement method may be prone to
9	information bias. With the questionnaire data we could have random misclassification error of
10	bicycle commuting and PA due to the data being self-reported. Therefore, the risk estimate
11	and also the potential mediation by PA could be an under-estimation (47). The TAPAS Travel
12	Survey only measured levels of PA without differentiating between travel PA (being most
13	accurate for commute studies) and other types of PA (work, recreational). Furthermore, the
14	modification of the 5-point PSS-4 Likert scale into a 4-point Likert scale could incorrectly-
15	estimate the perceived stress.
16	
17	This study has several strengths, too. The study has high internal validity, with a good
18	representation of bicycle commuters. Related to participants' characteristics (socio-
19	demographics), the TAPAS Travel Survey sample is representative of Barcelona's population.
20	It was compared with data from the Catalan government's Barcelona Active Population
21	Survey (Statistics and information service, Catalan government 2011) and no statistically
22	significant differences between participants' deprivation index and home and work population
23	density in both surveys were found (24,31). Finally, our study in a southern European city has
24	added evidence on these issues in a different context than the current literature.
25	

1 Future research

Our findings underscored the need for future research. There is a need to obtain a clear understanding of the relationship between bicycle commuting and perceived stress in longitudinal studies. The role of PA in this relationship seems unclear, and it is likely that other factors could affect the relationship between these two variables, especially those related to environmental determinants and personal attitudes. Further work related to determinants and mediators of bicycle commuting and perceived stress is needed.

8 CONCLUSIONS

We found that healthy, adult bicycle commuters had lower risk of being stressed than commuters of other transport modes. Also, bicycle commuters who bicycled four or more days per week had a lower risk of being stressed than those who bicycled less than that. Environmental determinants such as the number of public bicycle stations and bikeability, and also personal attitudes, seem to have an influence on this relationship. Further research is needed in order to disentangle the relationship between bicycle commuting and perceived stress, and its determinants (individual and environmental) and potential mediators. Our findings suggest that decision-makers may promote bicycle commuting as a daily routine to reduce stress levels and improve public health and well-being.

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12 COMPETING INTERESTS

13 There are no conflicts of interest to be reported by the authors of this paper.

14 AUTHOR'S CONTRIBUTION

- 15 MJN and AdN obtained the funding and designed the study. IAP conducted the analyses and
- 16 drafted this version of the paper and received input from all other authors. All authors read
- 17 and commented on the paper and agreed with the final version.

18 DATA SHARING

- 19 Extra data is available by emailing the corresponding author (Ione Avila-Palencia:
- 20 ione.avila@isglobal.org).

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25	

SUPPLEMENTARY MATERIAL

Table S1. PSS4 questions used in TAPAS Travel Survey

Q218. In the last month, how often have you felt that you were unable to control important things in your life?

0	Never
1	Almost never
2	Nearly always
3	Always
997	Don't Know
998	Refuse to Answer

Q219. In the last month, how often have you felt confident about your ability to handle your personal problems?

0 Never
1 Almost never
2 Nearly always
3 Always
997 Don't Know
998 Refuse to Answer

Q220. In the last month, how often have you felt that things were going your way?

- Never
 Almost never
 Nearly always
 Always
 Always
 Don't Know
 Refuse to Answer
- *Q221.* In the last month, how often have you felt that difficulties were piling up so high that you could not overcome them?
 - Never
 Almost never
 Nearly always
 Always
 - 997 Don't Know
 - 998 Refuse to Answer

PSS-4 score	n	%	Cumulative %
0	90	11.61	11.61
1	125	16.13	27.74
2	129	16.65	44.39
3	151	19.48	63.87
4	144	18.58	82.45
5	38	4.90	87.35
6	33	4.26	91.61
7	12	1.55	93.16
8	28	3.61	96.77
9	5	0.65	97.42
10	11	1.42	98.84
11	3	0.39	99.23
12	4	0.52	99.74
13	1	0.13	99.87
14	1	0.13	100.00
Total	775	100.00	

Table S2. PSS4 score distribution in TAPAS Travel Survey sample

6 7 8

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Table S3. Descriptive analyses of participant perceived stress and its determinants

according to bicycle commuting levels and bicycle commuting propensity.

9																		
10		Bicycle commuting levels									Ricycle computing presentity							
11	Voriables		Low	Me	dium	H	ligh		U	willing	1	Villing	Infact	propensity	F	requent		
12	variables	n	(109)	((65) %	(2	224) %	p-value ^a	n	(230)	n	(160)	n	quent (109)	n	(289)	p-value ^a	
13	Outcome			-		-						,.				,.		
14	Stressed (median)(Yes)	49	45.37	12	19.05	57	26.15	< 0.001	107	46.93	55	34.81	49	45.37	69	24.56	< 0.001	
15																		
16	Individual determinants																	
10	Age (median; P25-P75)	36	28-42	36	28-45	35	29-41	0.777	37	30-46	36	29.5-45	36	28-42	35	29-41	0.111	
17	Total PA - min/week (median: P25-P75)	494.99	299.99-734.99	454.99	359.99-	484.99	339.99-	0.567	364.99	209.99-600.00	404.99	209.99-629.99	494.99	299.99-734.99	480.00	339.99-744.99	< 0.001	
18		240.00	134.99-480.00	294.99	189.99-	300.00	177.49-	0.092	90.00	0-244.99	90.00	0-240.00	240.00	134.99-480.00	300.00	179.99-450.00	< 0.001	
19	MVPA – min/week (median; P25-P/5)	120.00	0-224.99	90.00	390.00 0-199.99	102.50	4/9.99	0.386	45.00	0-150.00	0	0-127.50	120.00	0-224.99	90.00	225.00	< 0.001	
20	VPA – min/week (median; P25-P75)	49	44.95	33	50.77	94	41.96	0.446	151	65.65	83	51.88	49	44.95	127	43.94	-0.001	
21	Gender (woman)	19	17.59	7	10.77	30	13.39	0.412	16	6.96	25	15.63	19	17.59	37	12.80	<0.001	
21	Country of birth (non-Spanish)	17	15.60	10	15.38	24	10.71	0.364	24	10.43	29	18.13	17	15.60	34	11.76	0.014	
22	Education level (University studies completed or	81	74.31	50	76.92	173	77.23	0.836	161	70.00	86	53 75	81	74 31	223	77.16	<0.001	
23	equivalent-level education)	00	74.51	40	75.00	175	76.70	0.633	102	70.00	125	04.20	01	74.51	220	76.20	<0.001	
24	Living with family/partner	60 60	80.73 63.30	40	55.56	1/2	64.73	0.622	192	83.48	100	68.00	60 60	80.73 63.30	180	62 72	0.114	
25	Employed people in household (2-5)	09	03.30		55.50	14.3	04.73	0.410	132	00.09	109	00.99	09	05.50	100	02.72	0.568	
26	MEDEA index	25	22.11	22	25.29	75	22.49	0.027	81	25.22	40	20.62	25	22.11	08	22.01	0.000	
27	1st tertile (least deprived)	29	24.96	25	41.54	76	22.02		66	28.70	56	35.00	29	24.96	102	25.64		
20	2nd tertile	36	22.02	15	22.08	72	22.50		92	26.00	55	24.28	36	22.02	105	20.45		
20	3rd tertile (most deprived)	31	28.44	15	28.13	79	35.27	0.340	9/	40.87	57	35.85	31	28.44	97	33.68	0.128	
29	Children in household (Yes)	3	20.44	5	7.94	20	8.93	0.114	20	8 73	16	10.00	3	2 75	25	8 71	0.158	
30	Children <3 years in household (Yes)	43	39.45	27	41 54	113	50.45	0.123	90	39.13	50	31.25	43	39.45	140	48 44	0.150	
31	Self-perceived health (Very good/Excellent)		22.04				21.00	0.969	50	21.00	51	22.00		22.04	63	21.0	0.004	
32	BMI (Overweight/Obese)	25	22.94	14	21.54	49	21.88	0.158	73	31.88	7	32.08	25	22.94	25	21.8	0.021	
33	Chronic disease (Yes)	95	87.16	62	98.41	100	90.05	0.047	163	72 44	130	89.68	05	87.16	25	91.90	0.293	
24	Stress releasing (Agreement)	103	94.50	65	100.00	212	95.03	0.175	116	51.79	133	84 71	103	94 50	201	96.85	<0.001	
34	Bicycle trip enjoyment (Agreement)	105	74.50	05	100.00	212	10.10	0.175	110	51.77	155	04.71	105	94.50	211	70.05	<0.001	
35																		
36	Environmental determinants	3.73	1.97	3.43	1.70	3.13	1.52	0.044	4.42	2.35	4.32	2.11	3.73	1.97	3.20	1.56	< 0.001	
37	Commute distance, estimated (km) (mean;SD)																	
38	Public bicycle stations (mean;SD)	4.61	2.61	4.97	2.63	4.75	2.35	0.492	3.77	2.53	3.72	2.49	4.61	2.61	4.80	2.41	< 0.001	
30	Home, count in 400m buffer	4.89	2.96	5.89	3.11	5.39	3.05	0.124	4.36	2.96	4.71	3.35	4.89	2.96	5.50	3.06	< 0.001	
40	work/study, count in 400m burrer																	
40	Using suggests of 400m buffer	0.83	1.30	0.75	0.98	0.59	0.94	0.635	0.90	1.03	0.91	1.16	0.83	1.30	0.62	0.95	0.002	
41	Work/study, suggests of 400m buffer	0.60	0.82	0.37	0.57	0.58	0.90	0.136	0.68	1.11	0.74	1.01	0.60	0.82	0.53	0.84	0.328	
42	Commute route, average of PRA	0.95	0.94	0.76	0.83	0.87	0.81	0.322	1.10	1.11	1.02	0.98	0.95	0.94	0.84	0.81	0.236	
43	NO. and (many SD)																	
44	Home concentration in 400m huffer	74.76	18.70	77.24	16.14	78.40	17.90	0.186	75.59	17.08	74.51	17.20	74.76	18.70	78.14	17.49	0.063	
45	Work/ctudy_concentration in 400m buffer	76.49	21.63	83.02	18.82	77.81	21.37	0.091	78.50	23.84	78.64	24.11	76.49	21.63	79.00	20.90	0.727	
46	Commute route concentration in PPA	82.86	16.10	87.47	15.22	84.51	18.08	0.127	85.22	17.34	82.76	15.95	82.86	16.10	85.19	17.48	0.296	
40	Noise >55dP (magn:SD)																	
41	Home proportion in 400m buffer	78.73	13.39	77.65	9.77	78.63	11.54	0.554	79.03	11.00	78.39	11.01	78.73	13.39	78.41	11.16	0.847	
48	Work/study proportion in 400m buffer	81.64	13.60	80.04	13.80	79.32	15.04	0.468	78.46	15.47	80.00	13.94	81.64	13.60	79.48	14.75	0.434	
49	Commute route proportion in PBA	78.62	9.13	75.40	9.26	77.21	9.64	0.057	77.12	8.43	78.08	8.78	78.62	9.13	76.80	9.57	0.160	
50	Bikeability (mean:SD)																	
51	Home concentration in 400m buffer	6.29	1.44	6.49	1.23	6.54	1.27	0.330	5.88	1.45	6.00	1.45	6.29	1.44	6.53	1.26	< 0.001	
51	Work/study, concentration in 400m buffer	6.82	1.28	6.88	0.98	6.75	1.17	0.638	6.21	1.58	6.46	1.47	6.82	1.28	6.78	1.13	< 0.001	
52	Commute route, concentration in PBA	6.77	1.10	7.02	0.93	6.99	0.93	0.236	6.36	1.22	6.58	1.16	6.77	1.10	7.00	0.93	< 0.001	
53	DA Dissolution in RDA	initen M	VDA Madana	a to Misson		A ativity X	IDA Maria		A		1.1.1	/	Deneão		1. 1			

Intration in RRA Internet in RRA PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; MEDEA, Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómicas y Ambientales, in Spanish (Environmental and socioEconomic Inequalities in Mortality in small Spanish areas, translated to English); BMI, Body Mass Index; NDVI, Normalized Difference Vegetation Index; RBA, Route-By-Area. Data are n and %, unless otherwise noted. There are missing data in: Perceived stress (13; 1.65%), Total PA (5; 0.63%), Country of birth (1; 0.13%), Living with family/partner (1; 0.13%), Employed people in household (4; 0.51), Children in household (2; 0.25%), Children (3years old in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂ (20; 2.54%), ^aChi square test, except for Age, Total PA, MVPA, VPA, and all the Environmental determinants (U Mann Whitney test).

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- 59
- 60

Table S4. Sensitivity bivariate analyses of the relationship between participant

determinants and perceived stress (P75, P90).

Variable		Perceived stress	s (P75)	Perceived stress (P90)			
Valladic	RI	R (95% CI)	p-value	RI	R (95% CI)	p-value	
Individual determinants	1.00	(0.00, 1.02)	0.703	1.00	(0.07.1.02)	0.662	
Age	1.00	(0.99, 1.02)	0.793	1.00	(0.97, 1.02)	0.002	
Total PA - min/week	1.00	(0.99, 1.00)	0.113	1.00	(0.99, 1.00)	0.802	
MVPA - min/week	1.00	(0.99, 1.00)	0.197	1.00	(0.99, 1.00)	0.701	
VPA - min/week	1.00	(0.99, 1.00)	0.382	1.00	(0.99, 1.00)	0.743	
Gender (Woman)	1.41	(1.03, 1.93)	0.032	1.69	(1.04, 2.76)	0.035	
Country of birth (non-Spanish)	1.16	(0.75, 1.78)	0.515	1.14	(0.58, 2.24)	0.695	
Education level (University studies completed or	1.40	(0.99, 2.14)	0.051	1.04	(0.55, 2.04)	0.904	
equivalent-level education)	0.78	(0.57, 1.07)	0.119	0.80	(0.49, 1.30)	0.369	
Living with family/partner	1.00	(0.68, 1.47)	0.987	0.94	(0.53, 1.68)	0.841	
Employed people in household (2-5)	0.67	(0.50, 0.91)	0.011	0.75	(0.47, 1.20)	0.231	
MEDEA index							
1st tertile (least deprived)	1.00			1.00			
2nd tertile	1.42	(0.96, 2.11)	0.081	1.85	(0.99, 3.46)	0.054	
3rd tertile (most deprived)	1.45	(0.97, 2.14)	0.067	1.77	(0.94, 3.33)	0.076	
Children in household (Yes)	1.05	(0.76, 1.44)	0.778	0.92	(0.56, 1.51)	0.743	
Children <3 years in household (Yes)	0.61	(0.30, 1.25)	0.180	0.54	(0.17, 1.68)	0.289	
Self-perceived health (Very good/Excellent)	0.65	(0.47, 0.91)	0.011	0.88	(0.55, 1.42)	0.604	
BMI (Overweight/Obese)	1.08	(0.77, 1.51)	0.664	1.03	(0.61, 1.73)	0.922	
Chronic disease (Yes)	1.58	(1.01, 2.48)	0.047	1.66	(0.83, 3.32)	0.150	
Stress releasing (Agreement)	0.85	(0.57, 1.27)	0.423	0.94	(0.49, 1.79)	0.850	
Bicycle trip enjoyment (Agreement)	0.74	(0.52, 1.04)	0.085	0.79	(0.46, 1.37)	0.409	
Environmental determinants							
Commute distance, estimated (km)	1.07	(0.99, 1.14)	0.053	1.03	(0.92, 1.15)	0.620	
Public bicycle stations							
Home, count in 400m buffer	0.99	(0.93, 1.06)	0.770	0.94	(0.84, 1.04)	0.253	
Work/study_count in 400m buffer	0.96	(0.91, 1.01)	0.103	0.96	(0.89, 1.03)	0.242	
Greenness, NDVI							
Home average of 400m buffer	0.95	(0.79, 1.14)	0.557	1.04	(0.81, 1.33)	0.768	
Work/study_average of 400m buffer	1.09	(0.94, 1.27)	0.262	0.99	(0.74, 1.32)	0.936	
Commute route average of RBA	1.04	(0.88, 1.22)	0.655	1.18	(0.95, 1.47)	0.138	
NO ₂ pph		(0100) 1122)			(0.70, 0.00)		
Home concentration in 400m buffer	1.00	(0.99, 1.00)	0.390	1.00	(0.98, 1.01)	0.728	
Work/study_concentration in 400m buffer	0.99	(0.99, 1.00)	0.042	0.99	(0.98, 1.00)	0.076	
Commute route, concentration in RBA	1.00	(0.99, 1.01)	0.474	0.99	(0.97, 1.00)	0.138	
Noise >55dB	1.00	(0.99, 1.01)	0.777	0.77	-(0.27, 1.00)	0.150	
Home proportion in 400m buffer	1.01	(0.99, 1.02)	0.483	1.00	(0.98, 1.03)	0.845	
Work/study, proportion in 400m buffer	1.01	(0.99, 1.02)	0.549	1.00	(0.98, 1.03)	0.835	
Commute route proportion in DDA	1.00	(0.99, 1.01)	0.54	1.00	(0.98, 1.02)	0.035	
Commute route, proportion in KBA	1.00	(0.90, 1.01)	0.034	1.01	(0.90, 1.04)	0.444	
Bikeability	0.07	(0.87 1.08)	0.522	0.02	(0.78 1.00)	0.254	
Home, concentration in 400m burier	0.97	(0.87, 1.00)	0.552	0.92	(0.76, 1.09)	0.330	
work/study, concentration in 400m buffer	0.92	(0.82, 1.02)	0.108	0.89	(0.75, 1.07)	0.210	
Commute route concentration in RBA	0.88		0.055	0.81	(U NN (U 99)	0.042	

Commute route, concentration in RBA 0.68 (0.77, 1.00) 0.03 0.61 (0.06, 0.27) 0.042 PA, Physical Activity; MVPA, Moderate-to-Vigorous Physical Activity; VPA, Vigorous Physical Activity; MEDEA, Mortalidad en áreas pequeñas Españolas y Desigualdades socioEconómicas y Ambientales, in Spanish (Environmental and socioEconomic Inequalities in Mortality in small Spanish areas, translated to English); BMI, Body Mass Index; NDVI, Normalized Difference Vegetation Index; RBA, Route-By-Area. Complete case analysis excluding missing data of the variables of final models (Table S5; n=771). The variables that still present missing data and are not included in the final models are: Total PA (5; 0.63%), People living with in household (1; 0.13%), Children in household (2; 0.25%), Children <3years old in household (3; 0.38), BMI (2; 0.25%); Stress releasing (15; 1.90%), Bicycle trip enjoyment (12; 1.52%), Commute distance (20; 2.54%), Greenness (20; 2.54%), NO₂(20; 2.54%).

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Table S5. Sensitivity analyses with multivariate models assessing the relationship between bicycle commuting and participant

perceived stress (P75, P90).

7		<u>.</u>						<u>.</u>																	
8	Variable		Model 1 ^a			fodel 2 ^b	Perceived	stress (P7	5) Model 3 ^c			Iodel 4 ^d			Model 1 ^a			Model 2 ^b	Perceived st	ress (P90)	fodel 3 ^c			odel 4 ^d	
9		RR	(95% CI)	p-value	RR	(95% CI)	p-value	RI	R (95% CI)	p-value	RR	(95% CI)	p-value	RF	(95% CI)	p-value	RR	(95% CI)	p-value	RR	(95% CI)	p-value	RR	(95% CI)	p-value
10	All sample (771)																								
11	Non-bicycle commuters	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
12	Bicycle commuters	0.58	(0.42, 0.79)	0.001	0.58	(0.42, 0.79)	0.001	0.61	(0.44, 0.85)	0.004	0.64	(0.46, 0.90)	0.011	0.54	(0.33, 0.89)	0.014	0.56	(0.34, 0.93)	0.025	0.52	(0.31, 0.88)	0.014	0.56	(0.33, 0.95)	0.032
12	Bicycle commuting levels																								
13	Non-bicycle commuters (0 days)	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
14	Low-level bicycle commuters (1-3 days)	1.04	(0.71, 1.54)	0.832	1.03	(0.70, 1.53)	0.868	1.08	(0.73, 1.59)	0.708	1.10	(0.74, 1.64)	0.626	1.20	(0.68, 2.11)	0.535	1.22	(0.68, 2.21)	0.505	1.14	(0.63, 2.07)	0.662	1.18	(0.65, 2.14)	0.589
15	Medium-level bicycle commuters (4 days)	0.22	(0.07, 0.66)	<0.007	0.20	(0.07, 0.62)	0.005	0.21	(0.07, 0.65)	0.007	0.22	(0.07, 0.68)	0.009	0.15	(0.02, 1.05)	0.056	0.14	(0.02, 1.00)	0.050	0.14	(0.02, 0.95)	0.044	0.15	(0.02, 1.04) (0.17, 0.73)	0.054
16	Bicycle commuting propensity	0.15	(0.2), 0.70)	-0.001	0.10	(0.50, 0.72)	0.001	0.50	(0.02, 0.10)	0.005	0.02	(0.00, 0.02)	0.005	0.01	(0110, 0170)	0.001	0.50	(0.17, 0.75)	0.000	0.55	(0.15, 0.05)	0.001	0.55	(0.17, 0.75)	0.000
17	Unwilling non-bicycle commuters	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
10	Willing non-bicycle commuters	0.71	(0.47, 1.06)	0.090	0.74	(0.49, 1.10)	0.135	0.71	(0.48, 1.06)	0.095	0.72	(0.48, 1.08)	0.116	0.66	(0.35, 1.22)	0.183	0.70	(0.38, 1.30)	0.255	0.70	(0.37, 1.30)	0.253	0.71	(0.38, 1.35)	0.298
18	Infrequent bicycle commuters	0.92	(0.61, 1.38)	0.684	0.92	(0.61, 1.39)	0.695	0.94	(0.63, 1.43)	0.788	0.97	(0.64, 1.48)	0.890	1.03	(0.57, 1.87)	0.926	1.07	(0.57, 2.01)	0.831	1.00	(0.53, 1.88)	0.991	1.04	(0.54, 1.98)	0.915
19	Frequent bicycle commuters	0.35	(0.23, 0.54)	<0.001	0.36	(0.23, 0.55)	< 0.001	0.38	(0.24, 0.59)	<0.001	0.40	(0.25, 0.62)	<0.001	0.25	(0.12, 0.52)	< 0.001	0.27	(0.13, 0.56)	< 0.001	0.25	(0.12, 0.52)	<0.001	0.27	(0.13, 0.56)	<0.001
20	Bicycle commuters sample (387)																								
21	Low-level bicycle commuters (1-3 days)	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
22	Medium-level bicycle commuters (4 days)	0.21	(0.06, 0.66)	0.008	0.19	(0.06, 0.61)	0.005	0.19	(0.06, 0.60)	0.005	0.19	(0.06, 0.60)	0.004	0.12	(0.02, 0.92)	0.041	0.11	(0.02, 0.83)	0.032	0.11	(0.02, 0.80)	0.028	0.11	(0.02, 0.76)	0.026
22	High-level bicycle commuters (>=5 days)	0.43	(0.26, 0.73)	0.002	0.44	(0.26, 0.75)	0.002	0.44	(0.26, 0.75)	0.002	0.44	(0.26, 0.73)	0.002	0.28	(0.12, 0.65)	0.003	0.28	(0.12, 0.65)	0.003	0.27	(0.12, 0.64)	0.003	0.27	(0.12, 0.60)	0.001
23	Bicycle commuters propensity	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
24	Infrequent bicycle commuters	0.38	(0.23, 0.64)	< 0.001	0.38	(0.23, 0.63)	< 0.001	0.38	(0.23, 0.63)	< 0.001	0.38	(0.23, 0.62)	< 0.001	0.25	(0.11, 0.55)	0.001	0.24	(0.11, 0.55)	0.001	0.24	(0.10, 0.54)	0.001	0.23	(0.11, 0.51)	< 0.001
25	Non-bicycle commuters sample (384)																								
26	Bicycle commuters propensity																								
27	Unwilling non-bicycle commuters	1.00			1.00			1.00			1.00			1.00			1.00			1.00			1.00		
28	Willing non-bicycle commuters	0.71	(0.47, 1.06)	0.090	0.72	(0.48, 1.07)	0.106	0.67	(0.45, 1.00)	0.051	0.69	(0.46, 1.03)	0.068	0.66	(0.35, 1.22)	0.183	0.68	(0.36, 1.26)	0.222	0.68	(0.36, 1.26)	0.221	0.71	(0.37, 1.36)	0.300
20	^d Adjusted by Age, G	Gender, C	Country of birth,	, Employed	people i	n household, C	Chronic dise	ease, Self	-perceived heal	lth, MVPA,	, Public b	icycle stations	at work/stud	dy, Bikeabi	lity at work/stu	udy, Bikeab	ility at co	ommute route.	viouerate-to	- vigorou	is r ilysical Ac	livity (ivi v	ΓA).		
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STROBE Statement—	-checklist of item	s that should	be included in	n reports of	observational	studies

	Item No	Recommendation	Reported in page
Title and abstract	1	(<i>a</i>) Indicate the study's design with a commonly used term in the title or the abstract	Page 2
		(<i>b</i>) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2
Introduction			
Background/rati onale	2	Explain the scientific background and rationale for the investigation being reported	Pages 4, 5
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5
Methods			
Study design	4	Present key elements of study design early in the paper	Page 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Pages 6, 7
Participants	6	(a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	Pages 6, 7
		(b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Pages 7, 8, 9, 10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Pages 7, 8, 9, 10
Bias	9	Describe any efforts to address potential sources of bias	Pages 6, 7
Study size	10	Explain how the study size was arrived at	Pages 6, 7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Pages 7, 8, 9, 10
Statistical methods	12	(<i>a</i>) Describe all statistical methods, including those used to control for confounding	Page 10
		(b) Describe any methods used to examine subgroups and interactions	Page 10
		(c) Explain how missing data were addressed	Page 10
		(d) Cohort study—If applicable, explain how loss to follow-up was addressed Case-control study—If applicable, explain how matching of cases and controls was addressed Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	Page 10
		(<u>e</u>) Describe any sensitivity analyses	Pages 7, 8, 10

Continued on next page

Results			Reported in page
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 6
		(b) Give reasons for non-participation at each stage	Page 6
		(c) Consider use of a flow diagram	In previous papers
Descriptive	14*	(a) Give characteristics of study participants (eg demographic, clinical,	Pages 10, 11,
data		social) and information on exposures and potential confounders	12, 13, 14
		(b) Indicate number of participants with missing data for each variable of interest	Pages 6, 13, 14
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	-
Outcome data	15*	Cohort study—Report numbers of outcome events or summary measures	-
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	-
		Cross-sectional study—Report numbers of outcome events or summary measures	Pages 10, 11, 12, 13, 14
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted	Pages 15, 16,
		estimates and their precision (eg, 95% confidence interval). Make clear	17
		which confounders were adjusted for and why they were included	
		(b) Report category boundaries when continuous variables were categorized	Pages 7, 8
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and	Pages 3, 4, 5
		sensitivity analyses	of
			Supplementary material
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 20
Interpretation	20	Give a cautious overall interpretation of results considering objectives,	Pages 18, 19,
		limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	20, 21
Generalisability	21	Discuss the generalisability (external validity) of the study results	Pages 20
Other informati	on		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 22

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.