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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

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

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 randomly-selected 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”.

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

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, $NO_2$ 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).

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

| Variables | Total sample (788) | | Bicycle commuting status | | | | p-value[a] |
|---|---|---|---|---|---|---|---|
| | | | Non-bicycle commuters (390) | | Bicycle commuters (398) | | |
| | n | % | n | % | n | % | |
| **Outcome** | | | | | | | |
| Stressed (median) (Yes) | 280 | 35.53 | 162 | 41.97 | 118 | 30.33 | 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 | 79.47 | 356 | 90.59 | <0.001 |
| Bicycle trip enjoyment (Agreement) | 629 | 79.82 | 249 | 65.35 | 380 | 96.20 | <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 [IQR, (median;IQR)] | | | | | | | |
| 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;IQR) | | | | | | | |
| Home, concentration in 400m buffer | 6.34 | 2.25 | 77.06 | 10.86 | 77.34 | 12.51 | 0.924 |
| Work/study, concentration in 400m buffer | 6.92 | 2.01 | 5.94 | 2.25 | 6.69 | 1.87 | <0.001 |
| Commute route, concentration in RBA | 6.89 | 1.55 | 6.64 | 1.75 | 7.10 | 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 (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%), $NO_2$ (20; 2.54%) . [a]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 stress | |
|---|---|---|
| | OR (95% CI) | p-value |
| **Individual determinants** | | |
| Age | 1.00 (0.98, 1.01) | 0.493 |
| Total PA - min/week | 1.00 (0.99, 1.00) | 0.665 |
| MVPA - min/week | 1.00 (0.99, 1.00) | 0.102 |
| VPA - min/week | 1.00 (0.99, 1.00) | 0.664 |
| Sex (Female) | 1.98 (1.46, 2.67) | <0.001 |
| Country of brith (Yes) | 1.63 (1.06, 2.51) | 0.027 |
| Working status (Student) | 1.38 (0.91, 2.11) | 0.131 |
| Education level (University studies completed or Others) | 0.87 (0.64, 1.20) | 0.391 |
| Living with family/partner | 0.87 (0.60, 1.25) | 0.446 |
| Employed people in household (>2) | 0.62 (0.46, 0.84) | 0.002 |
| MEDEA index | | |
| 1st tertile (least deprived) | 1.00 | |
| 2nd tertile | 1.12 (0.78, 1.61) | 0.537 |
| 3rd tertile (most deprived) | 1.29 (0.90, 1.86) | 0.161 |
| Children in household (Yes) | 0.86 (0.63, 1.17) | 0.325 |
| Children <3 years in household (Yes) | 0.81 (0.47, 1.41) | 0.461 |
| Self-perceived health (Very good/Excellent) | 0.80 (0.59, 1.09) | 0.154 |
| BMI (Overweight/Obese) | 0.93 (0.67, 1.30) | 0.666 |
| Chronic disease (Yes) | 1.74 (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;IQR) | | |
| 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 <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%), $NO_2$ (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 statistically-significant 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.

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

| Variable | Perceived stress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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)** | | | | | | | | | | | | |
| 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 |

[a]Adjusted by Sex, Country of birth, Employed people in household, Chronic disease. [b]Adjusted by Sex, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). [c]Adjusted 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.

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

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?**

| | |
|---|---|
| **0** | *Never* |
| **1** | *Nearly never* |
| **2** | *Often* |
| **3** | *Ever* |
| **997** | Don't Know |
| **998** | 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 |

**Table S2**. Description of the individual and environmental determinants in TAPAS sample for Bicycle commuting levels and Bicycle commuting propensity.

| Variables | Bicycle commuting levels | | | | | | | Bicycle commuting propensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low (109) | | Medium (65) | | High (224) | | p-value | Unwilling (230) | | Willing (160) | | Infrequent (109) | | Frequent (289) | | p-value |
| | 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 | <0.001 |
| **Individual determinants** | | | | | | | | | | | | | | | | |
| Age (median; IQR) | 36 | 14 | 36 | 17 | 35 | 12 | 0.777 | 37 | 16 | 36 | 16 | 36 | 14 | 35 | 12 | 0.111 |
| 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 | <0.001 |
| 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 | <0.001 |
| 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 | <0.001 |
| 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 | <0.001 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 | 0.568 |
| MEDEA index | | | | | | | 0.627 | | | | | | | | | 0.660 |
| 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 | 0.128 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| **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 | <0.001 |
| 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 | <0.001 |
| Work/study, count in 400m buff | 5 | 4 | 6 | 3 | 5 | 4 | 0.124 | 4 | 4 | 5 | 5 | 5 | 4 | 5 | 3 | <0.001 |
| 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 | 0.002 |
| 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 | 0.328 |
| 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 | 0.236 |
| $NO_2$, 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 | 0.063 |
| 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 | 0.727 |
| 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 | 0.296 |
| 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 | 0.847 |
| 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 | 0.434 |
| 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 | 0.160 |
| 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 | <0.001 |
| 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 | <0.001 |
| Commute route, concentration in RBA | 6.86 | 1.38 | 7.23 | 0.99 | 7.15 | 1.29 | 0.236 | 6.59 | 1.83 | 6.77 | 1.54 | 6.86 | 1.38 | 7.16 | 1.23 | <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 (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%), $NO_2$ (20; 2.54%) . [a]Chi 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.

| Variable | Perceived stress (P75) | | | Perceived stress (P90) | | |
|---|---|---|---|---|---|---|
| | OR (95% CI) | | p-value | OR (95% CI) | | p-value |
| **Individual determinants** | | | | | | |
| Age | 1.00 | (0.98, 1.02) | 0.783 | 0.99 | (0.97, 1.02) | 0.674 |
| Total PA - min/week | 1.00 | (0.99, 1.00) | 0.057 | 1.00 | (0.99, 1.00) | 0.775 |
| MVPA - min/week | 1.00 | (0.99, 1.00) | 0.115 | 1.00 | (0.99, 1.00) | 0.673 |
| VPA - min/week | 1.00 | (0.99, 1.00) | 0.367 | 1.00 | (0.99, 1.00) | 0.728 |
| Sex (Female) | 1.51 | (1.04, 2.21) | 0.031 | 1.78 | (1.05, 3.01) | 0.034 |
| Country of birth (non-Spanish) | 1.19 | (0.70, 2.05) | 0.520 | 1.16 | (0.55, 2.43) | 0.696 |
| Working status (Student) | 1.61 | (0.98, 2.64) | 0.060 | 1.05 | (0.50, 2.19) | 0.904 |
| Education level (University studies completed or equivalent-level education) | 0.74 | (0.50, 1.09) | 0.122 | 0.78 | (0.46, 1.34) | 0.370 |
| Living with family/partner | 1.00 | (0.62, 1.60) | 0.987 | 0.94 | (0.50, 1.77) | 0.841 |
| Employed people in household (>2) | 0.62 | (0.42, 0.90) | 0.012 | 0.73 | (0.43, 1.22) | 0.232 |
| MEDEA index | | | | | | |
| 1st tertile (least deprived) | 1.00 | | | 1.00 | | |
| 2nd tertile | 1.53 | (0.95, 2.44) | 0.079 | 1.95 | (0.99, 3.82) | 0.053 |
| 3rd tertile (most deprived) | 1.56 | (0.97, 2.49) | 0.065 | 1.85 | (0.94, 3.66) | 0.074 |
| Children in household (Yes) | 1.06 | (0.72, 1.55) | 0.778 | 0.91 | (0.53, 1.56) | 0.743 |
| Children <3 years in household (Yes) | 0.56 | (0.25, 1.27) | 0.166 | 0.52 | (0.16, 1.70) | 0.280 |
| Self-perceived health (Very good/Excellent) | 0.60 | (0.40, 0.89) | 0.010 | 0.87 | (0.52, 1.47) | 0.603 |
| BMI (Overweight/Obese) | 1.10 | (0.73, 1.65) | 0.665 | 1.03 | (0.58, 1.82) | 0.922 |
| Chronic disease (Yes) | 1.79 | (0.98, 3.28) | 0.059 | 1.77 | (0.80, 3.90) | 0.160 |
| Stress releasing (Agreement) | 0.82 | (0.49, 1.35) | 0.428 | 0.93 | (0.46, 1.89) | 0.850 |
| Bicycle trip enjoyment (Agreement) | 0.68 | (0.44, 1.06) | 0.092 | 0.78 | (0.42, 1.42) | 0.412 |
| **Environmental determinants** | | | | | | |
| Commute distance, estimated (km) | 1.09 | (0.99, 1.18) | 0.061 | 1.03 | (0.91, 1.16) | 0.621 |
| Public bicycle stations | | | | | | |
| Home, count in 400m buffer | 0.99 | (0.92, 1.06) | 0.761 | 0.93 | (0.84, 1.04) | 0.204 |
| Work/study, count in 400m buffer | 0.95 | (0.89, 1.01) | 0.088 | 0.95 | (0.87, 1.04) | 0.254 |
| Greenness, NDVI [IQR, (median;IQR)] | | | | | | |
| Home, average of 400m buffer | 0.94 | (0.78, 1.13) | 0.487 | 1.04 | (0.83, 1.31) | 0.726 |
| Work/study, average of 400m buffer | 1.11 | (0.93, 1.34) | 0.254 | 0.99 | (0.75, 1.29) | 0.924 |
| Commute route, average of RBA | 1.05 | (0.86, 1.27) | 0.643 | 1.20 | (0.95, 1.52) | 0.119 |
| $NO_2$, ppb (median;IQR) | | | | | | |
| Home, concentration in 400m buffer | 1.00 | (0.98, 1.01) | 0.379 | 1.00 | (0.98, 1.01) | 0.738 |
| Work/study, concentration in 400m buffer | 0.99 | (0.98, 1.00) | 0.048 | 0.99 | (0.98, 1.00) | 0.087 |
| Commute route, concentration in RBA | 1.00 | (0.98, 1.01) | 0.447 | 0.99 | (0.97, 1.00) | 0.077 |
| Noise, >55dB (%) (median;IQR) | | | | | | |
| Home, proportion in 400m buffer | 1.01 | (0.99, 1.02) | 0.417 | 1.00 | (0.98, 1.03) | 0.814 |
| Work/study, proportion in 400m buffer | 1.00 | (0.99, 1.02) | 0.539 | 1.00 | (0.98, 1.02) | 0.828 |
| Commute route, proportion in RBA | 1.00 | (0.98, 1.02) | 0.854 | 1.01 | (0.98, 1.04) | 0.422 |
| Bikeability (median;IQR) | | | | | | |
| Home, concentration in 400m buffer | 0.96 | (0.84, 1.10) | 0.528 | 0.92 | (0.77, 1.09) | 0.325 |
| Work/study, concentration in 400m buffer | 0.90 | (0.79, 1.02) | 0.097 | 0.88 | (0.74, 1.05) | 0.162 |
| Commute route, concentration in RBA | 0.85 | (0.73, 1.00) | 0.051 | 0.79 | (0.64, 0.98) | 0.030 |

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 <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%), $NO_2$ (20; 2.54%).

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

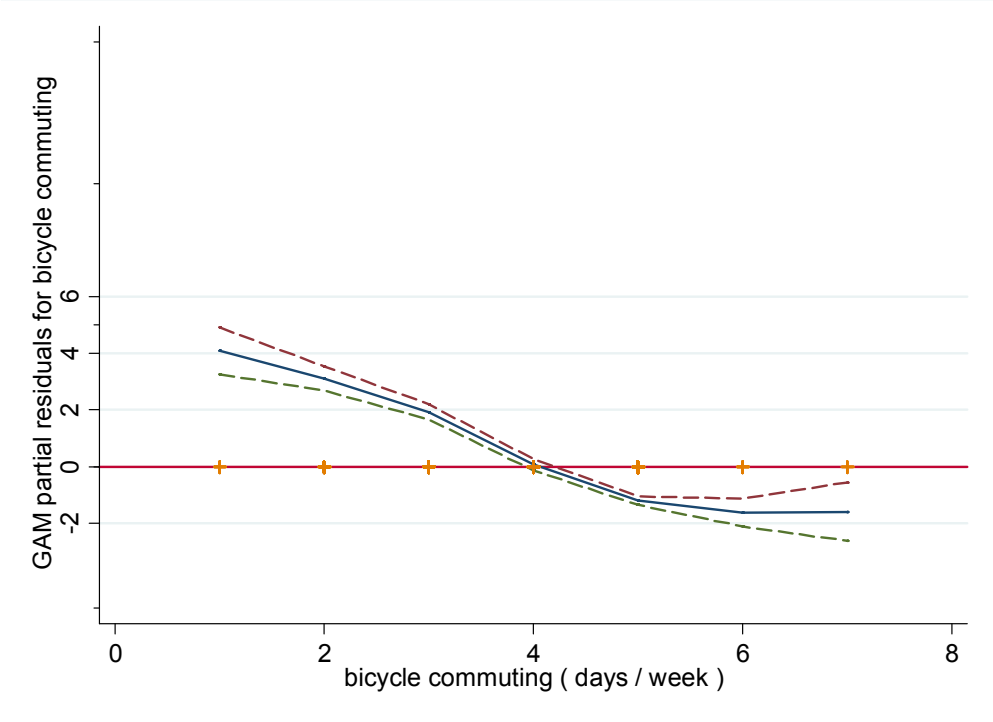

**Table S4**. Sensitivity analyses looking the relationship between bicycle commuting (Bicycle commuting status, Bicycle commuting levels, Bicycle commuting propensity) and perceived stress (P75, P90).

| Variable | Perceived stress (P75) | | | | | | | | | | | | Perceived stress (P90) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 | 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)** | | | | | | | | | | | | | | | | | | | | | | | | |
| 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) | 0.031 |
| 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) | 0.573 |
| 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) | 0.048 |
| High bicycle 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) | 0.007 |
| Bicycle commuting propensity | | | | | | | | | | | | | | | | | | | | | | | | |
| Unwilling Non-bicycle commuters | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| Willing Non-bicycle 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) | 0.289 |
| Infrequent Bicycle commuters | 0.89 | (0.52, 1.53) | 0.682 | 0.89 | (0.51, 1.56) | 0.691 | 0.92 | (0.52, 1.62) | 0.773 | 0.96 | (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) | 0.901 |
| Frequent 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) | 0.001 |
| **Bicycle commuters sample (387)** | | | | | | | | | | | | | | | | | | | | | | | | |
| Bicycle commuting levels | | | | | | | | | | | | | | | | | | | | | | | | |
| Low bicycle commuting (1-3 days) | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| 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) | 0.025 |
| 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 | 0.37 | (0.19, 0.70) | 0.002 | 0.25 | (0.10, 0.62) | 0.003 | 0.25 | (0.10, 0.62) | 0.003 | 0.24 | (0.09, 0.60) | 0.002 | 0.24 | (0.09, 0.60) | 0.003 |
| Bicycle 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) | 0.001 |
| **Exposure Non-bicycle commuters sample (384)** | | | | | | | | | | | | | | | | | | | | | | | | |
| Non-bicycle commuters | | | | | | | | | | | | | | | | | | | | | | | | |
| Unwilling | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| Willing | 0.64 | (0.39, 1.06) | 0.085 | 0.65 | (0.38, 1.09) | 0.104 | 0.59 | (0.35, 1.00) | 0.051 | 0.60 | (0.35, 1.03) | 0.062 | 0.62 | (0.31, 1.24) | 0.179 | 0.64 | (0.32, 1.31) | 0.225 | 0.64 | (0.31, 1.31) | 0.223 | 0.67 | (0.33, 1.38) | 0.275 |

[a]Adjusted by Sex, Country of birth, Employed people in household, Chronic disease. [b]Adjusted by Age, Sex, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). [c]Adjusted by Age, 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. Data were collected from June 2011 through to May 2012 in Barcelona, Spain.

STROBE Statement—checklist of items that should be included in reports of observational studies

| | Item No | Recommendation | Reported in page |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) 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/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | Pages 3, 4 |
| 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 recruitment, exposure, follow-up, and data collection | Pages 4, 5 |
| Participants | 6 | (*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up<br>*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<br>*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants | Pages 4, 5 |
| | | (*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed<br>*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 5, 6, 7, 8 |
| 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 5, 6, 7, 8 |
| 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 variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | Pages 5, 6, 7, 8 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | Page 8 |
| | | (*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 addressed<br>*Case-control study*—If applicable, explain how matching of cases and controls was addressed<br>*Cross-sectional study*—If applicable, describe analytical methods taking | Page 8 |

| | |
|---|---|
| | account of sampling strategy |
| | (*e*) Describe any sensitivity analyses Page 8 |

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 | In previous papers |
| | | (b) Give reasons for non-participation at each stage | In previous papers |
| | | (c) Consider use of a flow diagram | In previous papers |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Pages 8, 9, 10 |
| | | (b) Indicate number of participants with missing data for each variable of interest | Pages 8, 9, 10 |
| | | (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 measures | Pages 9,11 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | Pages 12, 13 |
| | | (*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 sensitivity analyses | Page 12, 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 or imprecision. Discuss both direction and magnitude of any potential bias | Pages 15, 16 |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Pages 14, 15, 16, 17 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | Pages 15, 16 |
| **Other information** | | | |
| 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 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.

BMJ Open

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



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| | |

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

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**Keywords**: Environmental epidemiology, Physical activity, Stress, Urbanisation, Self-rated health

**Word count of main text**: 3562

# 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 commuters or non-bicycle commuters, and based on the Perceived Stress Scale (PSS-4), as stressed or non-stressed. Multivariate Poisson regression with robust variance models of stress status based on bicycling exposure, adjusting for potential confounders, were estimated.

**Results:** Bicycle commuters had significantly lower risk of being stressed [RR (95%CI) = 0.73 (0.60, 0.89)]. Bicycle commuters who bicycled four or more days per week had lower risk of being stressed than those who bicycled less than four days. This relationship remained statistically significant after adjusting for individual and environmental 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.

# 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 home neighbourhood deprivation 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 physical activity because of the data being self-reported.

# 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).

Some literature recognises commuting as a potential source of stress(15); however, active commuters have been shown to have higher levels of satisfaction, lower stress, higher

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 account environmental determinants. Moreover, most studies of active commuting benefits on mental health have been conducted in North America or Northwest Europe, where the urban design tends to be less dense than many parts of the world(6,7,17,28–30). Consequently, a need exists to understand the relationship between bicycle commuting and perceived stress, particularly in dense urban environments.

The current study aimed to evaluate the relationship between bicycle commuting among the working or studying adult population and perceived stress in a dense urban setting.

# 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 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).

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 commuting

The TAPAS Travel Survey assessed the regular use of transport modes(32) and the bicycle use(33). Participants who indicated using a bicycle (private or from public bicycle sharing system) to go to work or school at least once the week prior to survey administration were classified as "bicycle commuters". Participants who did not commute by bicycle in the week prior to survey administration were classified as "non-bicycle commuters".

As part of the sensitivity analyses, commuting behaviour was further classified according to bicycle commuting levels and bicycle commuting propensity(24). Bicycle commuting levels classification was based on the days of bicycle commuting in the week prior to survey administration: "low" being three days or fewer, "medium" for four days, and "high" for five or more days. This measure could be interpreted as a proxy of bicycle commuting frequency. Bicycle commuting propensity classification took into account both frequency and willingness to commute by bicycle:the "bicycle commuters" were further classified as "frequent" (four or more days) or "infrequent" (three or less days), and the "non-bicycle commuters" were classified as "willing" or "unwilling". The "willing" group were those "non-bicycle commuters" who indicated bicycling as "never or nearly never" their general transport mode, but who also indicated that they would consider bicycle commuting in Barcelona (they answered positively to "considering costs, travelling time, comfort and safety, how ready would you be to use the bicycle/Bicing (public bicycle-sharing system) for 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 of being willing to commute by bicycle in perceived stress.

## 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 75$^{th}$ percentile (P75) and above (a score higher than 4) and in the 90$^{th}$ percentile (P90) and above (a score of 6 and above) as stressed and all others as non-stressed.

## 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 $NO_2$ levels were estimated 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 calculated taking into account five factors shown to influence bicycling: bicycle facility availability, bicycle facility quality, street connectivity, topography, and land use(39). 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

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 participants 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); men; have higher levels of PA; possess a university or equivalent-level education; live alone and/or with flat mates with 0-1 employed people; have no children; and have better self-perception of health, and healthy weight, but more chronic diseases than non-bicycle commuters. 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. Bicycle commuters had shorter commutes compared to non-bicycle commuters, and we observed a gradient between commute distance and bicycle commuting levels with shorter distances for those who cycled more frequently. This tendency was also followed by bicycle commuting propensity, with decreasing commute distance from unwilling to bicycle to frequent bicyclists (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 to non-bicycle commuters (Table 1). These environmental determinants stayed statistically significant for bicycle commuting propensity, but not between bicycle commuting levels (Table S3).

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 address area and on the commute route were less likely to be stressed. There was no statistically significant relationship between commute distance, greenness, $NO_2$ 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 [RR: 1.00; 95% CI: (0.99, 1.00)] for the three different classifications of perceived stress (P50, P75, P90) (Table 2, Table S4).

**Table 1**. Descriptive analyses of perceived stress and determinants of participants and according to bicycle commuting status.

| Variables | Total sample (788) | | Bicycle commuting status | | | | p-value[a] |
|---|---|---|---|---|---|---|---|
| | | | Non-bicycle commuters (390) | | Bicycle commuters (398) | | |
| | 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 | <0.001 |
| 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 |
| Sex (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 |
| 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 (2-5) | 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 | 6.41 | 36 | 9.05 | 0.166 |
| Stress releasing (Agreement) | 658 | 83.50 | 302 | 79.47 | 356 | 90.59 | <0.001 |
| Bicycle trip enjoyment (Agreement) | 629 | 79.82 | 249 | 65.35 | 380 | 96.20 | <0.001 |
| **Environmental determinants** | | | | | | | |
| 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, 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 route, proportion in RBA | 77.40 | 9.04 | 77.51 | 8.58 | 77.30 | 9.48 | 0.924 |
| Bikeability (mean;SD) | | | | | | | |
| 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; 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%), $NO_2$ (20; 2.54%). [a]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 | | |
|---|---|---|---|
| | RR (95% CI) | | 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 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 <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%), $NO_2$ (20; 2.54%).

Multivariate Poisson regression with robust variance analyses showed a statistically significant inverse relationship between bicycle commuting and perceived stress. Bicycle commuters had a lower risk of being stressed compared to non-bicycle commuters [RR (95%CI) = 0.73 (0.60, 0.89)]. This relationship remained after adjusting for confounders (individual and environmental) and when using P75 and P90 perceived stress cut-offs (Table 3, Table S5). There was a statistically significant inverse relationship between medium and high levels of bicycle commuting and perceived stress using non-bicycle commuters as a reference group [RR (95%CI) = 0.46 (0.28, 0.78); RR (95%CI) = 0.63 (0.49, 0.81)] and also when using low levels of bicycle commuting [RR (95%CI) = 0.42 (0.24, 0.73); RR (95%CI) = 0.57 (0.42, 0.77)] as a reference group. This statistically significant relationship remained in the majority of sensitivity analyses Regarding bicycle commuting propensity, there was a statistically significant inverse relationship between frequent bicycle commuters and perceived stress, using unwilling non-bicycle commuters [RR (95%CI) = 0.53 (0.41, 0.67)] and infrequent bicycle commuters [RR (95%CI) = 0.54 (0.40, 0.72)] as respective reference groups. The statistically significant relationship remained after adjusting for individual and environmental confounders and when using perceived stress P75 and P90 as cut-offs . Also, there was a statistically significant inverse relationship between willing non-bicycle commuters and perceived stress, using unwilling non-bicycle commuters [RR (95%CI) = 0.72 (0.56, 0.94)] as a reference group in the bicycle commuting propensity variable and also looking only in the non-bicycle commuting group. This relationship remained after adjusting for individual and environmental confounders, but not when using perceived stress at the P75 and P90 cut-offs.

In the fully adjusted models, we found no statistically significant interactions between gender and bicycle commuters (p-value= 0.165) between gender and bicycle commuting levels (p-

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

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

| Variable | Perceived stress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RR Unadjusted (95% CI) | | p-value | RR Adjusted[a] (95% CI) | | p-value | 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 |

[a]Adjusted by Gender, Country of birth, Employed people in household, Chronic disease. [b]Adjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). [c]Adjusted by Age, Gender, 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

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.

## 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

case physical activity did not act as a mediator in this relationship. Our sample was composed of young, healthy, and active participants with low levels of perceived stress, which might have led to an underestimation of the relationship between PA and perceived stress.

Qualitative research 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 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 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 more pleasant an environment to bicycle commute is, better perceived stress results 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 bicycling and stress was unchanged after controlling for the environmental confounders. Our results also 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 becomes statistically no significant 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. 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.

### 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.

## 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

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

## AUTHOR'S CONTRIBUTION

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

**Table S2**. PSS4 score distribution in TAPAS Travel Survey sample

| 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 S3**. Description of the individual and environmental determinants in TAPAS sample for Bicycle commuting levels and Bicycle commuting propensity.

| Variables | Bicycle commuting levels | | | | | | | Bicycle commuting propensity | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low (109) | | Medium (65) | | High (224) | | p-value | Unwilling (230) | | Willing (160) | | Infrequent (109) | | Frequent (289) | | p-value |
| | 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 | <0.001 |
| **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 | 0.111 |
| 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 | <0.001 |
| 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 | <0.001 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| MEDEA index | | | | | | | 0.627 | | | | | | | | | 0.660 |
| 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 | 0.128 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| **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 | <0.001 |
| 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 | <0.001 |
| 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 |
| 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 | 0.002 |
| 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 |
| 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 |
| $NO_2$, 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 | 0.063 |
| 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 | 0.727 |
| 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 | 0.296 |
| 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 | 0.847 |
| 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 |
| 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 | 0.160 |
| 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 | <0.001 |
| 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 |
| 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 | <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 (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%), $NO_2$ (20; 2.54%). [a]Chi square test, instead of 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 (P75) | | | Perceived stress (P90) | | |
|---|---|---|---|---|---|---|
| | RR (95% CI) | | p-value | RR (95% CI) | | p-value |
| **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) | 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 |
| $NO_2$, 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 <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%), $NO_2$ (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).

| Variable | Perceived stress (P75) | | | | | | | | | | | | Perceived stress (P90) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RR Unadjusted (95% CI) | | p-value | RR Adjusted[a] (95% CI) | | p-value | RR Adjusted[b] (95% CI) | | p-value | RR Adjusted[c] (95% CI) | | p-value | RR Unadjusted (95% CI) | | p-value | RR Adjusted[a] (95% CI) | | p-value | 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 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| 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 |
| 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) | 1.04 | (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) | 0.573 |
| 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 |
| 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 |
| Bicycle commuting propensity | | | | | | | | | | | | | | | | | | | | | | | | |
| Unwilling Non-bicycle commuters | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| 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 |
| 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 |
| 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 |
| **Bicycle commuters sample (387)** | | | | | | | | | | | | | | | | | | | | | | | | |
| Bicycle commuting levels | | | | | | | | | | | | | | | | | | | | | | | | |
| Low bicycle commuting (1-3 days) | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| 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 |
| 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 |
| Bicycle 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) | 0.38 | (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 |
| **Exposure Non-bicycle commuters sample (384)** | | | | | | | | | | | | | | | | | | | | | | | | |
| Non-bicycle commuters | | | | | | | | | | | | | | | | | | | | | | | | |
| Unwilling | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| 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 |

[a]Adjusted by Gender, Country of birth, Employed people in household, Chronic disease. [b]Adjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). [c]Adjusted by Age, Gender, 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. Data were collected from June 2011 through to May 2012 in Barcelona, Spain.

STROBE Statement—checklist of items that should be included in reports of observational studies

| | Item No | Recommendation | Reported in page |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) 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/rationale | 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<br>*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<br>*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<br>*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 | (*a*) 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<br>*Case-control study*—If applicable, explain how matching of cases and controls was addressed<br>*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy | Page 10 |
| | | (*e*) 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 data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Pages 10, 11, 12, 13, 14 |
| | | (b) Indicate number of participants with missing data for each variable of interest | Pages 6, 13, 14 |
| | | (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 measures | Pages 10, 11, 12, 13, 14 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | Pages 15, 16, 17 |
| | | (*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 sensitivity analyses | Pages 3, 4, 5 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, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Pages 18, 19, 20, 21 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | Pages 20 |
| **Other information** | | | |
| 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.

BMJ Open

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

| | |
|---|---|
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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/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 commuters or non-bicycle commuters, and based on the Perceived Stress Scale (PSS-4), as stressed or non-stressed. Multivariate Poisson regression with robust variance models of stress status based on bicycling exposure, adjusting for potential confounders, were estimated.

**Results:** Bicycle commuters had significantly lower risk of being stressed [RR (95%CI) = 0.73 (0.60, 0.89), p-value=0.001]. Bicycle commuters who bicycled four or more days per week had lower risk of being stressed than those who bicycled less than four days. This relationship remained statistically significant after adjusting for individual and environmental 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.

# 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 home neighbourhood deprivation 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 physical activity because of the data being self-reported.

# 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).

Some literature recognises commuting as a potential source of stress(15); however, active commuters have been shown to have higher levels of satisfaction, lower stress, higher

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 account environmental determinants. Moreover, most studies of active commuting benefits on mental health have been conducted in North America or Northwest Europe, where the urban design tends to be less dense than many parts of the world(6,7,17,28–30). Consequently, a need exists to understand the relationship between bicycle commuting and perceived stress, particularly in dense urban environments.

The current study aimed to evaluate the relationship between bicycle commuting among the working or studying adult population and perceived stress in a dense urban setting.

# 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 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).

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 commuting

The TAPAS Travel Survey assessed the regular use of transport modes(32) and the bicycle use(33). Participants who indicated using a bicycle (private or from public bicycle sharing system) to go to work or school at least once the week prior to survey administration were classified as "bicycle commuters". Participants who did not commute by bicycle in the week prior to survey administration were classified as "non-bicycle commuters".

As part of the sensitivity analyses, commuting behaviour was further classified according to bicycle commuting levels and bicycle commuting propensity(24). Bicycle commuting levels classification was based on the days of bicycle commuting in the week prior to survey administration: "low" being three days or fewer, "medium" for four days, and "high" for five or more days. This measure could be interpreted as a proxy of bicycle commuting frequency. Bicycle commuting propensity classification took into account both frequency and willingness to commute by bicycle: the "bicycle commuters" were further classified as "frequent" (four or more days) or "infrequent" (three or less days), and the "non-bicycle commuters" were classified as "willing" or "unwilling". The "willing" group were those "non-bicycle commuters" who indicated bicycling as "never or nearly never" their general transport mode, but who also indicated that they would consider bicycle commuting in Barcelona (they answered positively to "considering costs, travelling time, comfort and safety, how ready would you be to use the bicycle/Bicing (public bicycle-sharing system) for 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 of being willing to commute by bicycle in perceived stress.

## 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 75$^{th}$ percentile (P75) and above (a score higher than 4) and in the 90$^{th}$ percentile (P90) and above (a score of 6 and above) as stressed and all others as non-stressed.

## 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 $NO_2$ levels were estimated 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 calculated taking into account five factors shown to influence bicycling: bicycle facility availability, bicycle facility quality, street connectivity, topography, and land use(39). 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

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 participants 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); men; have higher levels of PA; possess a university or equivalent-level education; live alone and/or with flat mates with 0-1 employed people; have no children; and have better self-perception of health, and healthy weight, but more chronic diseases than non-bicycle commuters. 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. Bicycle commuters had shorter commutes compared to non-bicycle commuters, and we observed a gradient between commute distance and bicycle commuting levels with shorter distances for those who cycled more frequently. This tendency was also followed by bicycle commuting propensity, with decreasing commute distance from unwilling to bicycle to frequent bicyclists (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 to non-bicycle commuters (Table 1). These environmental determinants stayed statistically significant for bicycle commuting propensity, but not between bicycle commuting levels (Table S3).

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 address area and on the commute route were less likely to be stressed. There was no statistically significant relationship between commute distance, greenness, $NO_2$ 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).

**Table 1**. Descriptive analyses of perceived stress and determinants of participants and according to bicycle commuting status.

| Variables | Total sample (788) | | Bicycle commuting status | | | | p-value[a] |
|---|---|---|---|---|---|---|---|
| | | | Non-bicycle commuters (390) | | Bicycle commuters (398) | | |
| | 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 | <0.001 |
| 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 |
| 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 (2-5) | 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 | 6.41 | 36 | 9.05 | 0.166 |
| Stress releasing (Agreement) | 658 | 83.50 | 302 | 79.47 | 356 | 90.59 | <0.001 |
| Bicycle trip enjoyment (Agreement) | 629 | 79.82 | 249 | 65.35 | 380 | 96.20 | <0.001 |
| **Environmental determinants** | | | | | | | |
| 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, 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 route, proportion in RBA | 77.40 | 9.04 | 77.51 | 8.58 | 77.30 | 9.48 | 0.924 |
| Bikeability (mean;SD) | | | | | | | |
| 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 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%), $NO_2$ (20; 2.54%). [a]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 | | |
|---|---|---|---|
| | RR (95% CI) | | 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 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; 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 <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%), $NO_2$ (20; 2.54%).

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

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

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

| Variable | Perceived stress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RR Unadjusted (95% CI) | | p-value | RR Adjusted[a] (95% CI) | | p-value | 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 |

[a]Adjusted by Gender, Country of birth, Employed people in household, Chronic disease. [b]Adjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). [c]Adjusted by Age, Gender, 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

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.

## 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

case physical activity did not act as a mediator in this relationship. Our sample was composed of young, healthy, and active participants with low levels of perceived stress, which might have led to an underestimation of the relationship between PA and perceived stress.

Qualitative research 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 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 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 more pleasant an environment to bicycle commute is, better perceived stress results 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 bicycling and stress was unchanged after controlling for the environmental confounders. Our results also 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 becomes statistically no significant 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. 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.

### 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.

## 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

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

## AUTHOR'S CONTRIBUTION

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

**Table S2**. PSS4 score distribution in TAPAS Travel Survey sample

| 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 S3**. Description of the individual and environmental determinants in TAPAS sample for Bicycle commuting levels and Bicycle commuting propensity.

| Variables | Bicycle commuting levels | | | | | | | Bicycle commuting propensity | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low (109) | | Medium (65) | | High (224) | | p-value | Unwilling (230) | | Willing (160) | | Infrequent (109) | | Frequent (289) | | p-value |
| | 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 | <0.001 |
| **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 | 0.111 |
| 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 |
| MVPA – min/week (median; P25-P75) | 240.00 | 134.99-480.00 | 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 | <0.001 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| MEDEA index | | | | | | | 0.627 | | | | | | | | | 0.660 |
| 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 | 0.128 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| **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 | <0.001 |
| 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 | 3.72 | 2.49 | 4.61 | 2.61 | 4.80 | 2.41 | <0.001 |
| 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 |
| 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 | 0.002 |
| 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 |
| 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 |
| $NO_2$, 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 | 0.063 |
| 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 | 0.727 |
| 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 | 0.296 |
| 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 | 0.847 |
| 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 |
| 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 | 0.160 |
| 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 | <0.001 |
| 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 |
| 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 | <0.001 |

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%), $NO_2$ (20; 2.54%). [a]Chi 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 (P75) | | | Perceived stress (P90) | | |
|---|---|---|---|---|---|---|
| | RR (95% CI) | | p-value | RR (95% CI) | | p-value |
| **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) | 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 |
| $NO_2$, 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; 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%), $NO_2$ (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).

| Variable | Perceived stress (P75) | | | | | | | | | | | | Perceived stress (P90) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RR Unadjusted (95% CI) | | p-value | RR Adjusted[a] (95% CI) | | p-value | RR Adjusted[b] (95% CI) | | p-value | RR Adjusted[c] (95% CI) | | p-value | RR Unadjusted (95% CI) | | p-value | RR Adjusted[a] (95% CI) | | p-value | 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 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| 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 |
| 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) | 1.04 | (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 |
| 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 |
| 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 |
| Bicycle commuting propensity | | | | | | | | | | | | | | | | | | | | | | | | |
| Unwilling Non-bicycle commuters | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| 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 |
| 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 |
| 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 |
| **Bicycle commuters sample (387)** | | | | | | | | | | | | | | | | | | | | | | | | |
| Bicycle commuting levels | | | | | | | | | | | | | | | | | | | | | | | | |
| Low bicycle commuting (1-3 days) | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| 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 |
| 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 |
| Bicycle 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) | 0.38 | (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 |
| **Exposure Non-bicycle commuters sample (384)** | | | | | | | | | | | | | | | | | | | | | | | | |
| Non-bicycle commuters | | | | | | | | | | | | | | | | | | | | | | | | |
| Unwilling | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | |
| 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 |

[a]Adjusted by Gender, Country of birth, Employed people in household, Chronic disease. [b]Adjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). [c]Adjusted by Age, Gender, 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.

STROBE Statement—checklist of items that should be included in reports of observational studies

| | Item No | Recommendation | Reported in page |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) 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/rationale | 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<br>*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<br>*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<br>*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 | (*a*) 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<br>*Case-control study*—If applicable, explain how matching of cases and controls was addressed<br>*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy | Page 10 |
| | | (*e*) 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 data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Pages 10, 11, 12, 13, 14 |
| | | (b) Indicate number of participants with missing data for each variable of interest | Pages 6, 13, 14 |
| | | (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 measures | Pages 10, 11, 12, 13, 14 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | Pages 15, 16, 17 |
| | | (*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 sensitivity analyses | Pages 3, 4, 5 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, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Pages 18, 19, 20, 21 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | Pages 20 |
| **Other information** | | | |
| 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.

BMJ Open

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



| | |
|---|---|
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| Keywords: | EPIDEMIOLOGY, MENTAL HEALTH, PUBLIC HEALTH |
| | |

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

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**Keywords**: Bicycling, Commuting, Physical activity, Stress,Survey

**Word count of main text**: 4243

# 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; however, there are no studies examining the relationship between solely 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 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 (excluding those who only commuted on foot) in Barcelona, Spain. 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 either stressed or non-stressed. Multivariate Poisson regression with robust variance models of stress status based on exposures with bicycle commuting were estimated, and adjusted for potential confounders. **Results:** Bicycle commuters had significantly lower risk of being stressed than non-bicycle commuters [RR (95%CI) = 0.73 (0.60, 0.89), p-value=0.001]. Bicycle commuters who bicycled four days per week [RR (95%CI) = 0.42 (0.24, 0.73), p-value=0.002] and those who bicycled five or more days per week [RR (95%CI) = 0.57 (0.42, 0.77), p-value<0.001] had lower risk of being stressed than those who bicycled less than four days. This relationship remained statistically significant after adjusting for individual and environmental confounders, and when using different cut-offs 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.

# 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 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 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 physical activity due to the data being self-reported.

# 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).

Some literature recognises commuting as a potential source of stress (15); however, active commuters have been shown to have higher levels of satisfaction, lower stress, higher

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 a 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 solely bicycle commuting and perceived stress (global and comprehensive stress construct) in adults, nor taking into account environmental determinants. Moreover, most studies of active commuting and its beneficial effects on mental health have been conducted in North America, where the urban design tends to be less dense than many parts of the world, or Northwest Europe (6,7,17,28–30). Consequently, a need exists to understand the relationship between bicycle commuting and perceived stress, particularly in dense, Mediterranean/Southern European urban environments.

The current study aimed to evaluate the relationship between bicycle commuting and perceived stress among the working or studying adult population of a dense, Mediterranean/Southern European urban setting.

# 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 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).

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 commuting

The TAPAS Travel Survey assessed the regular use of transport modes (32), including bicycles (33). Participants who indicated using a bicycle (private or from a public bicycle sharing system) to go to work or school at least once the week prior to survey administration were classified as "bicycle commuters". Participants who did not commute by bicycle in the week prior to survey administration were classified as "non-bicycle commuters".

As part of the sensitivity analyses, commuting behaviour was further classified according to bicycle commuting levels and bicycle commuting propensity (24). Classification of bicycle commuting levels was based on the days of bicycle commuting in the week prior to survey administration: "low-level" being three days or fewer, "medium-level" for four days, and "high-level" for five or more days. This measure could be interpreted as a proxy of bicycle commuting frequency. Bicycle commuting propensity classification took into account both frequency and willingness to commute by bicycle: the "bicycle commuters" were further classified as "frequent" (four or more days) or "infrequent" (three or less days), and the "non-bicycle commuters" were classified as "willing" or "unwilling". The "willing" group were those "non-bicycle commuters" who indicated bicycling as "never or nearly never" their general transport mode, but who also indicated that they would consider bicycle commuting in Barcelona (by answering positively to "considering costs, travelling time, comfort and safety, how ready would you be to use the bicycle/Bicing (public bicycle-sharing system) for 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 75$^{th}$ percentile (P75) and above (a score higher than 4) and in the 90$^{th}$ percentile (P90) and above (a score of 6 and above) as stressed and all others as non-stressed.

## 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 $NO_2$ levels were estimated 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 calculated taking into account five factors shown to influence bicycling: bicycle facility availability, bicycle facility quality, street connectivity, topography, and land use (39). 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

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-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

Whitney tests) 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 (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

to non-bicycle commuters (Table 1). These environmental determinants stayed statistically significant for bicycle commuting propensity, but not between bicycle commuting levels (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, $NO_2$ 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).

**Table 1**. Descriptive analyses of participant perceived stress and its determinants as a total sample and according to bicycle commuting status.

| Variables | Total sample (788) | | Bicycle commuting status | | | | p-value[a] |
|---|---|---|---|---|---|---|---|
| | | | Non-bicycle commuters (390) | | Bicycle commuters (398) | | |
| | 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 | <0.001 |
| 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 |
| 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 (2-5) | 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 | 6.41 | 36 | 9.05 | 0.166 |
| Stress releasing (Agreement) | 658 | 83.50 | 302 | 79.47 | 356 | 90.59 | <0.001 |
| Bicycle trip enjoyment (Agreement) | 629 | 79.82 | 249 | 65.35 | 380 | 96.20 | <0.001 |
| **Environmental determinants** | | | | | | | |
| 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, 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 route, proportion in RBA | 77.40 | 9.04 | 77.51 | 8.58 | 77.30 | 9.48 | 0.924 |
| Bikeability (mean;SD) | | | | | | | |
| 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 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%), $NO_2$ (20; 2.54%). [a]Chi square test, except for Age, Total PA, MVPA, VPA, and all the Environmental determinants (U Mann Whitney test).

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

| Variable | Perceived stress (median) | | |
|---|---|---|---|
| | RR (95% CI) | | 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 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; 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 <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%), $NO_2$ (20; 2.54%).

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

significant in the adjusted models [Model 2: RR (95%CI) = 0.55 (0.43, 0.70), p-value<0.001; Model 3: RR (95%CI) = 0.56 (0.43, 0.72), p-value<0.001; Model 4: RR (95%CI) = 0.58 (0.45, 0.76), p-value<0.001] (Table 3) and when using perceived stress cut-offs of either P75 or P90 (Table S5). Also, "willing" non-bicycle commuters had lower risk of being stressed than "unwilling" non-bicycle commuters [Model 1: RR (95%CI) = 0.72 (0.56, 0.94), p-value=0.014]. This relationship remained statistically significant in the adjusted models [Model 2: RR (95%CI) = 0.75 (0.58, 0.97), p-value=0.029; Model 3. RR (95%CI) = 0.74 (0.57, 0.96), p-value=0.022; Model 4: RR (95%CI) = 0.75 (0.58, 0.97), p-value=0.031] (Table 3), but not when using perceived stress cut-offs of either P75 or P90 (Table S5).

When considering bicycle commuting levels within the bicycle commuters only sample, "medium-level" and "high-level" bicycle commuters had lower risk of being stressed than "low-level" bicycle commuters ["Medium-level" - Model 1: RR (95%CI) = 0.42 (0.24, 0.73), p-value=0.002. "High-level" - Model 1: RR (95%CI) = 0.57 (0.42, 0.77), p-value<0.001]. These relationships remained statistically significant in the adjusted models (["Medium-level" - Model 2: RR (95%CI) = 0.39 (0.23, 0.67), p-value=0.001; Model 3: RR (95%CI) = 0.39 (0.23, 0.65), p-value<0.001; Model 4: RR (95%CI) = 0.38 (0.23, 0.65), p-value<0.001. "High-level" - Model 2: RR (95%CI) = 0.59 (0.44, 0.80), p-value=0.001; Model 3: RR (95%CI) = 0.59 (0.44, 0.80), p-value=0.001; Model 4: RR (95%CI) = 0.59 (0.44, 0.80), p-value=0.001) (Table 3) and when using perceived stress cut-offs of either P75 or P90 (Table S5). Regarding bicycle commuting propensity, "frequent" bicycle commuters had lower risk of being stressed than "infrequent" bicycle commuters [Model 1: RR (95%CI) = 0.54 (0.40, 0.72), p-value<0.001]. This relationship remained statistically significant in the adjusted models [Model 2: RR (95%CI) = 0.55 (0.41, 0.73), p-value<0.001; Model 3: RR (95%CI) =

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] (Table 3) and when using perceived stress cut-offs of either P75 or P90 (Table S5).

Considering bicycle commuting propensity within the non-bicycle commuters only sample, "willing" non-bicycle commuters had lower risk of being stressed than "unwilling" non-bicycle commuters [Model 1: RR (95%CI) = 0.72 (0.56, 0.94), p-value=0.015]. This relationship remained statistically significant in the adjusted models [Model 2: RR (95%CI) = 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; Model 4: RR (95%CI) = 0.74 (0.57, 0.95), p-value=0.020] (Table 3), but not when using perceived stress cut-offs of either P75 or P90 (Table S5).

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

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

| Variable | Perceived stress (median) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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)** | | | | | | | | | | | | |
| 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 |

[a] Unadjusted. [b]Adjusted by Gender, Country of birth, Employed people in household, Chronic disease. [c]Adjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA). [d]Adjusted by Age, Gender, 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

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.

## Limitations and strengths

Our study has 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 due to the data being self-reported. Therefore, the risk estimate and also the potential mediation by PA could be an under-estimation (47). The TAPAS Travel Survey only measured levels of PA without differentiating between travel PA (being most accurate for commute studies) and other types of PA (work, 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 has several strengths, too. The study has high internal validity, with a good representation of bicycle commuters. Related to participants' characteristics (socio-demographics), the TAPAS Travel Survey sample is representative of Barcelona's population. 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 on these issues in a different context than the current literature.

### 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.

## 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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## COMPETING INTERESTS

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

## AUTHOR'S CONTRIBUTION

MJN and AdN obtained the funding and designed the study. IAP conducted the analyses and drafted this version of the paper and received input from all other 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 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 |

**Table S2**. PSS4 score distribution in TAPAS Travel Survey sample

| 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 S3**. Descriptive analyses of participant perceived stress and its determinants according to bicycle commuting levels and bicycle commuting propensity.

| Variables | Bicycle commuting levels | | | | | | | Bicycle commuting propensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low (109) | | Medium (65) | | High (224) | | p-value[a] | Unwilling (230) | | Willing (160) | | Infrequent (109) | | Frequent (289) | | p-value[a] |
| | 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 | <0.001 |
| **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 | 0.111 |
| 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 |
| MVPA – min/week (median; P25-P75) | 240.00 | 134.99-480.00 | 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 | <0.001 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| MEDEA index | | | | | | | 0.627 | | | | | | | | | 0.660 |
| 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 | 0.128 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| **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 | <0.001 |
| 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 | 3.72 | 2.49 | 4.61 | 2.61 | 4.80 | 2.41 | <0.001 |
| 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 |
| 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 | 0.002 |
| 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 |
| 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 |
| $NO_2$, 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 | 0.063 |
| 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 | 0.727 |
| 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 | 0.296 |
| 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 | 0.847 |
| 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 |
| 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 | 0.160 |
| 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 | <0.001 |
| 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 |
| 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 | <0.001 |

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%), $NO_2$ (20; 2.54%). [a]Chi square test, except for Age, Total PA, MVPA, VPA, and all the Environmental determinants (U Mann Whitney test).

**Table S4**. Sensitivity bivariate analyses of the relationship between participant determinants and perceived stress (P75, P90).

| Variable | Perceived stress (P75) | | | Perceived stress (P90) | | |
|---|---|---|---|---|---|---|
| | RR (95% CI) | | p-value | RR (95% CI) | | p-value |
| **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) | 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 |
| $NO_2$, 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; 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%), $NO_2$ (20; 2.54%).

**Table S5**. Sensitivity analyses with multivariate models assessing the relationship between bicycle commuting and participant perceived stress (P75, P90).

| Variable | Perceived stress (P75) | | | | | | | | | | Perceived stress (P90) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 | 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)** | | | | | | | | | | | | | | | | | | | | | | |
| Bicycle commuting status | | | | | | | | | | | | | | | | | | | | | | |
| Non-bicycle commuters | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | |
| Bicycle commuters | 0.58 | (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 |
| 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-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 |
| 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) | 0.054 |
| High-level bicycle commuters (>=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 |
| Bicycle commuting propensity | | | | | | | | | | | | | | | | | | | | | | |
| Unwilling non-bicycle commuters | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | |
| 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 |
| 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 |
| 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 |
| **Bicycle commuters sample (387)** | | | | | | | | | | | | | | | | | | | | | | |
| Bicycle commuting levels | | | | | | | | | | | | | | | | | | | | | | |
| Low-level bicycle commuters (1-3 days) | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | |
| 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 |
| 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 |
| Bicycle commuters propensity | | | | | | | | | | | | | | | | | | | | | | |
| Infrequent bicycle commuters | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | |
| Frequent 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 |
| **Non-bicycle commuters sample (384)** | | | | | | | | | | | | | | | | | | | | | | |
| Bicycle commuters propensity | | | | | | | | | | | | | | | | | | | | | | |
| Unwilling non-bicycle commuters | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | | 1.00 | | | 1.00 | | | 1.00 | | | 1.00 | |
| 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 |

[a]Unadjusted. [b]Adjusted by Gender, Country of birth, Employed people in household, Chronic disease. [c]Adjusted by Age, Gender, Country of birth, Employed people in household, Chronic disease, Self-perceived health, Moderate-to-Vigorous Physical Activity (MVPA).
[d]Adjusted by Age, Gender, 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.

STROBE Statement—checklist of items that should be included in reports of observational studies

| | Item No | Recommendation | Reported in page |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) 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/rationale | 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<br>*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<br>*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<br>*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 | (*a*) 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<br>*Case-control study*—If applicable, explain how matching of cases and controls was addressed<br>*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy | Page 10 |
| | | (*e*) 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 data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Pages 10, 11, 12, 13, 14 |
| | | (b) Indicate number of participants with missing data for each variable of interest | Pages 6, 13, 14 |
| | | (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 measures | Pages 10, 11, 12, 13, 14 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | Pages 15, 16, 17 |
| | | (*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 sensitivity analyses | Pages 3, 4, 5 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, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Pages 18, 19, 20, 21 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | Pages 20 |
| **Other information** | | | |
| 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.