What is the role of particulate matter 2.5 ($PM_{2.5}$) on excess weight: a cross-sectional study in young Spanish people aged 2─14 years?

José Francisco López-Gil[1], PhD; Sitong Chen[2], PhD; Lee Smith[3], PhD; Héctor Gutiérrez-Espinoza[4], PhD; Desirée Victoria-Montesinos PhD[5]; Javier Nieto Iglesias, PhD[6], Pedro Juan Tárraga-López, PhD[7]; Arthur Eumann Mesas, PhD[1,8]

[1] Health and Social Research Center, Universidad de Castilla-La Mancha, Cuenca, Spain.
[2] Institute for Health and Sport, Victoria University, Melbourne, Australia.
[3] Centre for Health, Performance and Wellbeing, Anglia Ruskin University, Cambridge, United Kingdom.
[4] Escuela de Fisioterapia, Universidad de las Américas, Quito, 170504, Ecuador.
[5] Health Sciences Department, Universidad Católica San Antonio de Murcia (UCAM), Guadalupe, Murcia, Spain.
[6] Unidad de Hipertensión y Riesgo Vascular, Hospital General Universitario de Ciudad Real, Ciudad Real, Spain
[7] Departamento de Ciencias Médicas, Facultad de Medicina, Universidad Castilla-La Mancha (UCLM), Albacete, Spain.
[8] Postgraduate Program in Public Health, Universidade Estadual de Londrina, Londrina, Brazil.

Corresponding author:
* Héctor Gutiérrez-Espinoza, PhD.
🖂 Escuela de Fisioterapia, Universidad de las Américas, Quito, 170504, Ecuador.
🖰 kinehector@gmail.com

Abstract

Purpose: To assess the relationship between particulate matter 2.5 (PM2.5) levels and the prevalence of excess weight in a representative sample of Spanish young people aged 2‒14 years. **Methods:** This was an ecological cross-sectional study using data from the 2017 wave of the Spanish National Health Survey (SNHS), a nationally representative survey of the Spanish young and adult population. The final sample included 4378 young Spanish people (51.0% boys). The weight (kg) and height (cm) of the study participants were proxy-reported by parents or guardians. Excess weight was determined according to the age- and sex-criteria of the International Obesity Task Force. The $PM_{2.5}$ level was calculated as the annual monitoring data indicator for 2017 among the different regions in Spain. Logistic regression models were performed to estimate the relationships between $PM_{2.5}$ and weight. **Results:** Compared to young people located in regions with low levels of $PM_{2.5}$, those reporting greater odds for excess weight were found in regions with medium $PM_{2.5}$ (OR=1.23; 95% CI, 1.02–1.49) and high $PM_{2.5}$ (OR=1.35; 95% CI, 1.11–1.64) after adjusting for several sociodemographic, lifestyle and environmental covariates. **Conclusions:** The prevalence of excess weight in young people was positively associated with $PM_{2.5}$ levels in Spain. This finding supports the hypothesis that air pollution exposure can result in excess weight in the young population, which, in turn, might lead to the development of metabolic disorders. From a socioecological perspective, a practical need to take environmental factors into consideration is important to address unhealthy weight in Spanish young people.

Keywords: Air pollution; overweight; obesity; preschoolers; children; youths.

1. Introduction

Obesity in young people has been a serious concern for a century owing to the related chronic and adverse health outcomes (Abarca-Gómez et al., 2017). Young people with obesity are at a much higher risk of experiencing some undesirable health outcomes in adult life, such as cardiovascular disease, hypertension, and type 2 diabetes (Lee & Yoon, 2018). In European countries, excess weight prevalence estimates are worrisome, with the majority of countries reporting a prevalence of 20% or higher (Stival et al., 2022). In relation to Spain, the newly published data from Estudio ALADINO 2019 (2020) showed a prevalence of excess weight (overweight plus obesity), overweight, and obesity of 32.9%, 10.9%, and 22.0%, respectively (based on the International Obesity Task Force cutoff points (Cole & Lobstein, 2012)), among Spanish children aged 6-9 years. Moreover, a longitudinal study by de Bont et al. (2022) found that the overall prevalence of Spanish childhood obesity increased from 0.8% at two years of age (in both sexes) to a peak at seven years of age in girls (17.3%) and at nine years of age in boys (24.1%). Despite this high prevalence, the World Health Organization has estimated that no European countries will achieve the proposed targets of reversing rising levels of excess weight by 2025 (Mahase, 2022). It is therefore vital to efficiently develop specific interventions and policies to curb overweight and obesity in Europe. To develop such interventions, correlates of overweight and obesity need to be identified. While there is a plethora of known correlates of overweight and obesity, one potentially important but understudied of them is air pollution.

From a socioecological perspective, one of the critical environmental elements of morbidity and mortality worldwide is air pollution (Khomenko et al., 2021). In this sense, the Global Burden of Disease 2015 reported that air pollution exposure adversely influences people’s health, which means the loss of more years of life and millions of deaths every year in comparison with other recognized health risk factors (e.g., smoking, unhealthy dietary patterns) (World Health Organization, 2021). Recent estimates denote that releases of most ambient air pollutants will increase further over time, and consequently, emissions of certain pollutants (e.g., particulate matter 2.5 [$PM_{2.5}$]) may rise in the majority of the world's regions by 2060 (Organization for Economic Cooperation and Development, 2016). Among others, one of the groups most vulnerable to the short-term damage of ambient air pollutants is young people (Goudie, 2014). Specifically, exposure to certain ambient air pollutants (e.g., $PM_{2.5}$) is associated with numerous adverse effects on the health of young people, such as obesity (Tamayo-Ortiz et al., 2021), hypertension (Huang et al., 2020), decreased pulmonary function (Garcia et al., 2021), and/or wheezing/asthma (Yan et al., 2020),

Some studies have reported a link between $PM_{2.5}$ concentration and excess weight among young populations in different countries (Bloemsma et al., 2019; de Bont et al., 2019; Tamayo-Ortiz et al., 2021; Tong et al., 2022; Vrijheid et al., 2020; Wilding et al., 2020). For example, one systematic review and meta-analysis by Parasin et al. (2021) found strong observational evidence supporting the hypothesis that exposure to environmental pollution is one of the related factors to excess weight in young people. Similarly, one study by Tong et al. (2022) showed (from pregnancy to late childhood) a dose–response association between exposure to $PM_{2.5}$ and excess weight in China (i.e., for each additional five $\mu g/m^3$ of $PM_{2.5}$, the probability was 26% higher), confirming the cumulative effect of environmental pollution on excess weight among young Chinese people. Conversely, one prospective cohort study among Italian children found no association between exposure to vehicular traffic and exposure to pollutants on obesity-related parameters (e.g., body mass index) (Fioravanti et al., 2018). Additionally, another study showed that exposure to $PM_{2.5}$ levels was associated with lower rather than higher body mass index z scores (Fleisch et al., 2017). Because of this mixed evidence concerning the association between $PM_{2.5}$ concentration and excess weight among young populations, it seems necessary to further explore this association in specific populations. This accumulation can help determine the actual association between $PM_{2.5}$ and excess weight. In relation to Spain, a previous study analyzed this association (de Bont et al., 2019); however, this study only included one city and is thus limited to research generalizability. To our knowledge, there is no study in Spain examining the relationship between $PM_{2.5}$ levels and excess weight at the national level. Similarly, there is a lack of studies exploring the relationship among young people, and only eight studies were included in the previous meta-analysis (Parasin et al., 2021). In addition, most of the studies included in that meta-analysis controlled for associations by only a few covariates.

Given this background, this study tries to assess the association between $PM_{2.5}$ levels and the prevalence of excess weight in a representative sample of Spanish young people aged 2–14 years. According to previous studies (de Bont et al., 2019; Parasin et al., 2021), our hypothesis is that living in regions with higher $PM_{2.5}$ will be related to greater odds of having excess weight among young people in Spain.

2. Methods

2.1. Study design and participants

This is an ecological cross-sectional study using data from the 2017 wave of the *Encuesta Nacional de Salud Española* (ENSE) (Ministerio de Sanidad, Consumo y Bienestar Social, 2018), a nationally representative survey of Spanish young and adult populations. This survey was jointly carried out by the Ministerio de Sanidad, Consumo y Bienestar Social (2018) and the Instituto Nacional de Estadística (2018). The sampling framework considered noninstitutionalized Spanish citizens. The ENSE applies a three-stage sampling design: (a)

1st phase (census); (b) 2nd phase (households); (c) 3rd phase (citizens). An adult was chosen to complete the Adult Questionnaire (from each household), and to determine whether there were minors living in the households (up to 14 years old), one of them was selected (at random) to complete the Minors Questionnaire.

For this study, the sample was limited to young people (between 0 and 14 years old) with data available for the Minors Questionnaire. The initial sample involved 6106 (100%) minors. A total of 1728 participants (28.3%) were excluded because of missing data for any of the studied variables (independent variable, dependent variable, or covariates). Then, the analyzed sample contained 4378 (71.7%) Spanish young people from 2 to 14 years old. Further information on the different reasons for exclusion of participants can be found in Figure S1.

Data from ENSE (2017) were anonymized and acquired directly from the Ministerio de Sanidad, Consumo y Bienestar Social (2018) public access webpage (https://www.sanidad.gob.es/estadisticas/microdatos.do). Since this study included secondary data, ethics committee approval was not necessary.

2.2. Procedures

2.2.1. Excess weight (dependent variable)

Study participants' weight (kg) and height (cm) were proxy-declared by their parents/guardians, which were determined to calculate body mass index (BMI) and then converted into BMI z score based on the sex- and age-criteria of the International Obesity Task Force (Cole & Lobstein, 2012). In relation to BMI z score, minors were classified into four different groups: (a) thinness; (b) normal weight; (c) overweight; and (d) obesity. We focused on examining both overweight and obesity jointly. In addition, for further analysis, participants were considered "excess weight" ("overweight" + "obesity") or "no excess weight" ("thinness" + "normal weight"). This decision was based on two main reasons. First, the epidemic of excess weight (i.e., overweight and obesity) has been identified as a major challenge to health and chronic disease across the life course at the worldwide level (Hruby & Hu, 2015). Second, a high prevalence of excess weight was found in Europe (Stival et al., 2022) and in Spain (de Bont et al., 2022; Estudio ALADINO 2019, 2020).

2.2.2. Regional particulate matter 2.5 – $PM_{2.5}$ (independent variable)

Data on the level of $PM_{2.5}$ were collected based on the Spanish report of air quality by the Ministerio para la Transición Ecológica y el Reto Demográfico (2017). $PM_{2.5}$ was calculated as the annual monitoring data indicator for 2017. Competent administrations divide their territory into zones or agglomerations according to population density agglomerations (Ministerio para la Transición Ecológica y el Reto Demográfico, 2017). Zones are portions of territory delimited by the competent administration and are used for the evaluation and management of air quality. Agglomerations are defined as conurbations with a population of more than 250,000 inhabitants or, when the population is equal to or less than 250,000 inhabitants, with a population density per km^2 that, according to the competent administration, justifies the assessment and monitoring of ambient air quality. ambient air quality. To ensure the representativeness of the values, both the size of the populations and the ecosystems exposed to air pollution were considered. This information matched the data of the ENSE. In the absence of specific values for individual cities/municipalities, emissions of $PM_{2.5}$ (in $\mu g/m^3$) in each of the 17 regions (and their two autonomous cities) were used to categorize the air pollution level. Additionally, due to the lack of specific $\mu g/m^3$ $PM_{2.5}$ cutoff points, Spanish regions were categorized into tertiles: (a) low $PM_{2.5}$ tertile; (b) medium $PM_{2.5}$ tertile; and (c) high $PM_{2.5}$ tertile.

2.2.3. Covariates

Based on previous studies, we included the following factors as covariates when examining the association between $PM_{2.5}$ and excess weight (Cakmak et al., 2011; Chiu et al., 2016; Lacoste et al., 2020; López-Gil et al., 2022; Seo et al., 2020; Tainio et al., 2021).

2.2.3.1. Sociodemographic

Sex (boys/girls) and age were proxy-reported by parents/guardians of the study participants. Socioeconomic status (SES) was considered based on six different groups in relation to the responder's employment. Groups ranged from "class 1" (the highest) to "class 6" (the lowest). For analytical purposes, we collapsed these categories into (a) low SES (class 6 plus class 5), (b) medium SES (class 4 plus class 3), and (c) high SES (class 2 plus class 1).

2.2.3.2. Lifestyle

Sleep duration was computed through the next question: "Can you tell me approximately how many hours your child usually sleeps daily? (Counting nap time if applicable)". Recreational sedentary time (ST) was measured with a question related to the time spent both on weekdays and weekends: "How much time does your child typically spend on weekdays/weekends in front of a screen, including a computer, tablet, TV, video, video game or cell phone screen?". The following answers were available: (a) "nothing or almost nothing"; (b) "less than one hour"; (c) "one hour or more". If "one hour or more" was reported, parents/guardians were additionally asked about the exact hours their children spent with ST. Physical activity (PA) was evaluated with an adapted form of the International Physical Activity Questionnaire (Roman-Viñas et al., 2010). Four possible responses were available: (a) "no exercise" (free-time principally spent in sedentary behaviors [e.g., reading, watching TV]); (b) "occasional sport, or PA participation"; (c) "PA several times monthly", and (d) "physical training or sports several times weekly" (Ministerio de Sanidad, Consumo y Bienestar Social, 2018). Diet quality was evaluated with the Spanish Health Eating Index (S-HEI) (Norte Navarro & Ortiz Moncada, 2011). This is a modified form of the original Healthy Eating Index (HEI) (Kennedy et al., 1995), which involves ten different food groups separated into five categories of frequency of food intake: (a) “never or hardly ever”; (b) “one time per week”; (c) “from one to two times per week”; (d) “more than three times per week, but not daily”, and (e) “daily”. The global score for the S-HEI was calculated as the sum of the frequency of food group intake (from zero to ten points) and means adherence to the recommendations by the Sociedad Española de Nutrición Comunitaria (2016) (i.e., a greater S-HEI score depicts higher adherence to these recommendations).

2.2.3.3. Environmental

Tobacco smoke exposure was assessed with the following question: “How often is your child exposed to indoor tobacco smoke?”; the possible responses were (a) “never or almost never”; (b) “less than one hour daily”; (c) “from one to five hours daily”; and (d) “more than five hours daily”. For further analyses, we recoded these categories into (a) “no exposure” (“never or almost never”) or (b) “exposure” (“less than one hour daily”, “from one to five hours daily”, or “more than five hours daily”) (Schane et al., 2010).

2.3. Statistical analysis

Categorical data are shown as numbers and percentages, while continuous data are displayed as the mean and standard deviation. The Kolmogorov–Smirnov test and normal probability plot were applied to test the assumption of normality of continuous variables (i.e., age, sleep duration, recreational ST, S-HEI score, $PM_{2.5}$, weight, height, and BMI z score). One-way analyses of variance (ANOVAs) (with additional Dunnett's T3 test for post hoc analyses when applicable) or chi-square tests were applied to test differences between continuous or categorical data, respectively, between different $PM_{2.5}$ tertiles established and the participants' characteristics. Prior analyses indicated an absence of a significant interaction between sex or age and $PM_{2.5}$ levels in relation to excess weight (*p-for-interaction* >0.05 for both). Thus, all analyses were performed in overall samples. Odds ratios (ORs) and confidence intervals (CIs) were determined through logistic regression analyses, which were conducted to examine the association between different $PM_{2.5}$ tertiles established and excess weight. For this purpose, four different models were analyzed: "model 0" (crude); "model 1" (adjusted for age group, sex, and socioeconomic status); "model 2" (adjusted for model 1 + sleep duration, recreational screen time, physical activity, and diet quality); and "model 3" (adjusted for model 2 + tobacco smoke exposure). Furthermore, the same four models were performed in additional logistic regression analyses conducted to determine the change in the odds of the outcome (i.e., excess weight) for a one-unit increase in the exposure (i.e., continuous $PM_{2.5}$ level, in $\mu g/m^3$). All the analyses were performed with STATA 16.1 (StataCorp, College Station, TX, USA) considering the probability weights for each participant (i.e., *pweight* command) due to the random sampling without replacement used in the ENSE (2017). A $p<0.05$ was selected to indicate statistical significance.

3. Results

Table 1 displays the descriptive data of the study participants. The $PM_{2.5}$ mean was 10.13±1.79 (low $PM_{2.5}$), 12.45±0.43 (medium $PM_{2.5}$), and 16.69±2.75 (high $PM_{2.5}$). The excess weight prevalence was 40.9%, 38.5%, and 31.9% for the high, medium, and low $PM_{2.5}$ groups, respectively ($p<0.001$).

Table 1 near here

Figure 1 shows the BMI z score mean values of the $PM_{2.5}$ groups established. Study participants living in regions with high $PM_{2.5}$ had the highest BMI z score mean (M=0.61; SE=0.05). Conversely, participants from regions with low $PM_{2.5}$ showed the lowest BMI z score mean (M=0.39; SE=0.05). In addition, Dunnett's T3 tests for post hoc analysis showed significant differences between low $PM_{2.5}$ and high $PM_{2.5}$ (p=0.002), as well as between low $PM_{2.5}$ and medium $PM_{2.5}$ (p=0.003).

Figure 1 near here

Figure 2 depicts the association between the established $PM_{2.5}$ groups and excess weight among the young population. Compared to study participants living in regions with low levels of $PM_{2.5}$, a greater odds of having excess weight was found in those who lived in regions with medium levels of $PM_{2.5}$ (OR=1.23; CI95%, 1.02–1.49) and high levels of $PM_{2.5}$ (OR=1.35; CI95%, 1.11–1.64) after adjusting for several sociodemographic, lifestyle, and environmental covariates. The full results of the binary logistic analyses are shown as supplementary material in **Table S1 (**$PM_{2.5}$ as a categorical variable) and in **Table S2** ($PM_{2.5}$ as a continuous variable).

Figure 2 near here

4. Discussion

4.1. Key findings

Overall, our findings show that young people living in regions with medium and high $PM_{2.5}$ levels had greater BMI z scores than those who lived in regions with low $PM_{2.5}$ levels. Furthermore, we found greater odds of having excess weight in young people who lived in regions with medium or high $PM_{2.5}$ levels. These associations were found in both unadjusted and adjusted models, which denotes that the association between $PM_{2.5}$ levels and excess weight remains consistently significant regardless of several sociodemographic, lifestyle, and environmental covariates.

4.2. Comparisons with previous studies

Our results are consistent with a previous meta-analysis (Parasin et al., 2021), as well as studies conducted in different countries, such as Mexico (Tamayo-Ortiz et al., 2021), China (Tong et al., 2022), The Netherlands (Bloemsma et al., 2019), and England (Wilding et al., 2020). This finding is also in line with one previous study including different European countries (i.e., France, Greece, United Kingdom, Norway, Lithuania, and Spain) (Vrijheid et al., 2020). Regarding the previous study carried out in Spain (de Bont et al., 2019), although it included several ambient air pollutants (i.e., NO_2, PM_{10}, $PM_{2.5}$), their results are based on data from only the city of Barcelona, which prevents conclusive evidence concerning the association between the level of $PM_{2.5}$ within the entire Spanish context.

4.3. Interpretations of research findings

The etiology of obesity is complex (Torres-Carot et al., 2022), and its pathophysiological mechanisms reveal that obesity may be a result of genetic and environmental interactions (Blüher, 2019; Nicolaidis, 2019). Although the primary cause of excess weight is the unbalanced relationship between total energy intake and expenditure, an increasing interest in the role of environmental exposure (e.g., air pollution) on the obesity epidemic (Holtcamp, 2012) is emerging. There are some possible reasons that may justify the association between air pollution and excess weight in young people. Indeed, it has been observed that exposure to air pollution increases the risk of excess weight (An, Ji, et al., 2018; Toledo-Corral et al., 2018). Higher $PM_{2.5}$ levels could lead to metabolic dysfunction via insufficient physical activity, increased adipose tissue inflammation, oxidative stress, or risk of chronic comorbidities (An, Zhang, et al., 2018). Although physical activity did not remain significant in the fully adjusted models analyzing the relationship between $PM_{2.5}$ and excess weight in our study, we observed that the physical activity level was lower in regions with greater levels of $PM_{2.5}$, suggesting that low levels of physical activity (among other factors) may be responsible for excess weight in young people. Moreover, some studies have pointed out that exposure to air pollution could lead to disrupted molecular factors that preserve excess weight and may influence the incidence of diseases related to excess weight (Bolton et al., 2012). Worryingly, it has been hypothesized that $PM_{2.5}$ could lead to weight gain by increasing brain inflammation and, therefore, the probabilities of developing other noncommunicable diseases (e.g., respiratory diseases, cardiovascular diseases, or cancer) (McConnell et al., 2016).

Importantly, some covariates included in this study were associated with $PM_{2.5}$ categories, and they remained significantly associated when we introduced them into the model that analyzed the relationship between $PM_{2.5}$ levels and excess weight. Particularly, low SES was associated with excess weight. Although we used regional indicators of $PM_{2.5}$ levels instead of individual values, it has been suggested that the relationship between air pollution and excess weight is stronger among children living in the most deprived areas (de Bont et al., 2019). Conversely, although sleep duration was not associated with $PM_{2.5}$ categories, our adjusted analyses showed that this covariate was statistically significant in this relationship. This result is in line with a previous study among children in the US and

China (Lawrence et al., 2018), which suggested that air pollution may cause insufficient sleep, which, in turn, could lead to weight gain. We are not able to explain why each of these covariates predicts higher odds of having excess weight only for specific subjects, so further studies are needed to explore whether such specificities exist or whether they are random findings. However, our results indicate that the relationship between $PM_{2.5}$ and excess weight remained significant regardless of these covariates.

4.4. Methodological considerations

This study has some limitations that should be considered for the correct interpretation of the present findings. For instance, this is a cross-sectional design, and consequently, cause and effect relationships cannot be determined. Additionally, although we adjusted for several covariates, residual confounding is still possible, such as family history of obesity and other metabolic disorders, diagnosis and treatment of comorbidities, etc. However, it is unlikely that higher levels of overweight and obesity in the young increase air pollutants, so we could confirm that air pollutants might be a contributor to excess weight. Moreover, BMI and excess weight were assessed through proxy-reported weight and height (by parents/guardians). This may result in measurement inaccuracies. In addition, in this ecological study, $PM_{2.5}$ emissions in different regions were used instead of the individual exposure to $PM_{2.5}$ of each participant, which could lead to an ecological bias. However, it has been pointed out that this inaccuracy could be justified because of the slight influence related to the technique applied (Avery et al., 2010). However, air quality monitors may be a useful approach to compute $PM_{2.5}$ exposure at the individual level (Ong et al., 2019), at least in a subsample of the next Spanish National Health Survey. Furthermore, other air pollutants (Parasin et al., 2021), environmental noise (de Bont et al., 2021), or factors related to cities (de Bont et al., 2021) may also be linked with excess weight. For instance, other air pollutants (e.g., PM_{10} and NO_2) have also been linked to excess weight in young people (Parasin et al., 2021). Environmental noise may impact sleep deprivation and increase stress hormones, which are related to the physical development of young people, increasing the risk of excess weight (Münzel et al., 2016). An unhealthy food environment may increase the intake of fast food and possibly caloric intake, which is a well-known risk factor for excess weight in young people (Townshend & Lake, 2017). The strength of this study is that it provides new insights into the relationship between $PM_{2.5}$ levels and excess weight among Spanish young people, adding empirical evidence to the current literature. A further strength is the large nationwide sample of Spanish young people examined, which can enhance research generalization to the whole Spanish young population.

In conclusion, the regional $PM_{2.5}$ concentration seems to be related to the prevalence of excess weight in young Spanish people. This finding supports the hypothesis that exposure to ambient air pollution is associated with excess weight in young populations, which, in turn, might lead to the development of metabolic disorders (An, Ji, et al., 2018). However, further studies are needed to use a longitudinal study design to obtain stronger evidence in this research field. Since controlling air pollution seems to be linked with healthy weight in young people, public health organizations should consider strategies to counteract the health risks for young people in regions with great $PM_{2.5}$ emissions. Finally, findings from the present study support the adoption of the United Nations Sustainable Development Goal (SDG) 7 "ensure access to affordable, reliable, sustainable and modern energy for all" https://sdgs.un.org/goals/goal7 to also aid in the prevention of excess weight in the young population.

Acknowledgments

Dr. López-Gil is a Postdoctoral Fellow (Universidad de Castilla-La Mancha – ID 2021-UNIVERS-10414).

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Abarca-Gómez, L., Abdeen, Z. A., Hamid, Z. A., Abu-Rmeileh, N. M., Acosta-Cazares, B., Acuin, C., Adams, R. J., Aekplakorn, W., Afsana, K., Aguilar-Salinas, C. A., Agyemang, C., Ahmadvand, A., Ahrens, W., Ajlouni, K., Akhtaeva, N., Al-Hazzaa, H. M., Al-Othman, A. R., Al-Raddadi, R., Al Buhairan, F., … Ezzati, M. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: A pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. *The Lancet*, *390*(10113), 2627-2642. https://doi.org/10.1016/S0140-6736(17)32129-3

An, R., Ji, M., Yan, H., & Guan, C. (2018). Impact of ambient air pollution on obesity: A systematic review. *International Journal of Obesity*, *42*(6), 1112-1126. https://doi.org/10.1038/s41366-018-0089-y

An, R., Zhang, S., Ji, M., & Guan, C. (2018). Impact of ambient air pollution on physical activity among adults: A systematic review and meta-analysis. *Perspectives in Public Health*, *138*(2), 111-121. https://doi.org/10.1177/1757913917726567

Avery, C. L., Mills, K. T., Williams, R., McGraw, K. A., Poole, C., Smith, R. L., & Whitsel, E. A. (2010). Estimating Error in Using Residential Outdoor PM2.5 Concentrations as Proxies for Personal Exposures: A Meta-analysis. *Environmental Health Perspectives*, *118*(5), 673-678. https://doi.org/10.1289/ehp.0901158

Bloemsma, L. D., Wijga, A. H., Klompmaker, J. O., Janssen, N. A. H., Smit, H. A., Koppelman, G. H., Brunekreef, B., Lebret, E., Hoek, G., & Gehring, U. (2019). The associations of air pollution, traffic noise and green space with overweight throughout childhood: The PIAMA birth cohort study. *Environmental Research*, *169*, 348-356. https://doi.org/10.1016/j.envres.2018.11.026

Blüher, M. (2019). Obesity: Global epidemiology and pathogenesis. *Nature Reviews Endocrinology*, *15*(5), 288-298. https://doi.org/10.1038/s41574-019-0176-8

Bolton, J. L., Smith, S. H., Huff, N. C., Gilmour, M. I., Foster, W. M., Auten, R. L., & Bilbo, S. D. (2012). Prenatal air pollution exposure induces neuroinflammation and predisposes offspring to weight gain in adulthood in a sex-specific manner. *The FASEB Journal*, *26*(11), 4743-4754. https://doi.org/10.1096/fj.12-210989

Cakmak, S., Dales, R., Leech, J., & Liu, L. (2011). The influence of air pollution on cardiovascular and pulmonary function and exercise capacity: Canadian Health Measures Survey (CHMS). *Environmental Research*, *111*(8), 1309-1312. https://doi.org/10.1016/j.envres.2011.09.016

Chiu, Y.-H. M., Hsu, H.-H. L., Coull, B. A., Bellinger, D. C., Kloog, I., Schwartz, J., Wright, R. O., & Wright, R. J. (2016). Prenatal particulate air pollution and neurodevelopment in urban children: Examining sensitive windows and sex-specific associations. *Environment International*, *87*, 56-65. https://doi.org/10.1016/j.envint.2015.11.010

Cole, T. J., & Lobstein, T. (2012). Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity: Extended international BMI cut-offs. *Pediatric Obesity*, *7*(4), 284-294. https://doi.org/10.1111/j.2047-6310.2012.00064.x de Bont, J., Bennett, M., León-Muñoz, L. M., & Duarte-Salles, T. (2022). Prevalencia e incidencia de sobrepeso y obesidad en 2,5 millones de niños y adolescentes en España. *Revista Española de Cardiología*, *75*(4), 300-307. https://doi.org/10.1016/j.recesp.2021.06.030

de Bont, J., Casas, M., Barrera-Gómez, J., Cirach, M., Rivas, I., Valvi, D., Álvarez, M., Dadvand, P., Sunyer, J., & Vrijheid, M. (2019). Ambient air pollution and overweight and obesity in school-aged children in Barcelona, Spain. *Environment International*, *125*, 58-64. https://doi.org/10.1016/j.envint.2019.01.048

de Bont, J., Márquez, S., Fernández-Barrés, S., Warembourg, C., Koch, S., Persavento, C., Fochs, S., Pey, N., de Castro, M., Fossati, S., Nieuwenhuijsen, M., Basagaña, X., Casas, M., Duarte-Salles, T., & Vrijheid, M. (2021). Urban environment and obesity and weight-related behaviours in primary school children. *Environment International*, *155*, 106700. https://doi.org/10.1016/j.envint.2021.106700

Estudio ALADINO 2019. (2020). *Estudio sobre Alimentación, Actividad Física, Desarrollo Infantil y Obesidad en España 2019*. Agencia Española de Seguridad Alimentaria y Nutrición (Ministerio de Consumo). https://www.aesan.gob.es/AECOSAN/docs/documentos/nutricion/observatorio/Informe_Aladino_2019.pdf

Fioravanti, S., Cesaroni, G., Badaloni, C., Michelozzi, P., Forastiere, F., & Porta, D. (2018). Traffic-related air pollution and childhood obesity in an Italian birth cohort. *Environmental Research*, *160*, 479-486. https://doi.org/10.1016/j.envres.2017.10.003

Fleisch, A. F., Luttmann-Gibson, H., Perng, W., Rifas-Shiman, S. L., Coull, B. A., Kloog, I., Koutrakis, P., Schwartz, J. D., Zanobetti, A., Mantzoros, C. S., Gillman, M. W., Gold, D. R., & Oken, E. (2017). Prenatal and early life exposure to traffic pollution and cardiometabolic health in childhood. *Pediatric Obesity*, *12*(1), 48-57. https://doi.org/10.1111/ijpo.12106

Garcia, E., Rice, M. B., & Gold, D. R. (2021). Air pollution and lung function in children. *Journal of Allergy and Clinical Immunology*, *148*(1), 1-14. https://doi.org/10.1016/j.jaci.2021.05.006

Goudie, A. S. (2014). Desert dust and human health disorders. *Environment International*, *63*, 101-113. https://doi.org/10.1016/j.envint.2013.10.011

Holtcamp, W. (2012). Obesogens: An Environmental Link to Obesity. *Environmental Health Perspectives*, *120*(2). https://doi.org/10.1289/ehp.120-a62

Hruby, A., & Hu, F. B. (2015). The Epidemiology of Obesity: A Big Picture. *PharmacoEconomics*, *33*(7), 673-689. https://doi.org/10.1007/s40273-014-0243-x

Huang, C., Wang, Y., Li, X., Ren, L., Zhao, J., Hu, Y., Zhang, L., Fan, G., Xu, J., Gu, X., Cheng, Z., Yu, T., Xia, J., Wei, Y., Wu, W., Xie, X., Yin, W., Li, H., Liu, M., … Cao, B. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *The Lancet*, *395*(10223), 497-506. https://doi.org/10.1016/S0140-6736(20)30183-5

Instituto Nacional de Estadística. (2018). *Encuesta Nacional de Salud. Resultados*. https://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica_C&cid=1254736176783&menu=resultados&idp=1254735573175#!tabs-1254736195650

Kennedy, E. T., Ohls, J., Carlson, S., & Fleming, K. (1995). The Healthy Eating Index. *Journal of the American Dietetic Association*, *95*(10), 1103-1108. https://doi.org/10.1016/S0002-8223(95)00300-2

Khomenko, S., Cirach, M., Pereira-Barboza, E., Mueller, N., Barrera-Gómez, J., Rojas-Rueda, D., de Hoogh, K., Hoek, G., & Nieuwenhuijsen, M. (2021). Premature mortality due to air pollution in European cities: A health impact assessment. *The Lancet Planetary Health*, *5*(3), e121-e134. https://doi.org/10.1016/S2542-5196(20)30272-2

Lacoste, Y., Dancause, K. N., Gosselin-Gagne, J., & Gadais, T. (2020). Physical Activity Among Immigrant Children: A Systematic Review. *Journal of Physical Activity and Health*, *17*(10), 1047-1058. https://doi.org/10.1123/jpah.2019-0272

Lawrence, W. R., Yang, M., Zhang, C., Liu, R.-Q., Lin, S., Wang, S.-Q., Liu, Y., Ma, H., Chen, D.-H., Zeng, X.-W., Yang, B.-Y., Hu, L.-W., Yim, S. H. L., & Dong, G.-H. (2018). Association between long-term exposure to air pollution and sleep disorder in Chinese children: The Seven Northeastern Cities study. *Sleep*, *41*(9). https://doi.org/10.1093/sleep/zsy122

Lee, E. Y., & Yoon, K.-H. (2018). Epidemic obesity in children and adolescents: Risk factors and prevention. *Frontiers of Medicine*, *12*(6), 658-666. https://doi.org/10.1007/s11684-018-0640-1

López-Gil, J. F., García-Hermoso, A., Cavero-Redondo, I., Ortega, F. B., Gómez, S. F., & Martínez-Vizcaíno, V. (2022). Association between air pollution and 24-h movement behaviours in a representative sample of Spanish youth. *Environmental Research*, 113996. https://doi.org/10.1016/j.envres.2022.113996

Mahase, E. (2022). Obesity: No European country is on track to halt rising levels by 2025, WHO warns. *BMJ*, o1107. https://doi.org/10.1136/bmj.o1107

McConnell, R., Gilliland, F. D., Goran, M., Allayee, H., Hricko, A., & Mittelman, S. (2016). Does near-roadway air pollution contribute to childhood obesity?: Near-roadway pollution and childhood obesity. *Pediatric Obesity*, *11*(1), 1-3. https://doi.org/10.1111/ijpo.12016

Ministerio de Sanidad, Consumo y Bienestar Social. (2018). *Encuesta Nacional de Salud Española*. https://www.sanidad.gob.es/estadEstudios/estadisticas/encuestaNacional/encuestaNac2017/ENSE17_Metodologia.pdf

Ministerio para la Transición Ecológica y el Reto Demográfico. (2017). *Evaluación de la calidad del aire en España*. https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-del-aire/informeevaluacioncalidadaireespana2017_tcm30-481655.pdf

Münzel, T., Sørensen, M., Gori, T., Schmidt, F. P., Rao, X., Brook, F. R., Chen, L. C., Brook, R. D., & Rajagopalan, S. (2016). Environmental stressors and cardio-metabolic disease: Part II–mechanistic insights. *European Heart Journal*, ehw294. https://doi.org/10.1093/eurheartj/ehw294

Nicolaidis, S. (2019). Environment and obesity. *Metabolism*, *100*, 153942. https://doi.org/10.1016/j.metabol.2019.07.006

Norte Navarro, A. I., & Ortiz Moncada, R. (2011). [Spanish diet quality according to the healthy eating index]. *Nutricion Hospitalaria*, *26*(2), 330-336. https://doi.org/10.1590/S0212-16112011000200014

Ong, H., Holstius, D., Li, Y., Seto, E., & Wang, M. (2019). Air pollution and child obesity: Assessing the feasibility of measuring personal PM2.5 exposures and behaviours related to BMI in preschool-aged children in China. *Obesity Medicine*, *16*, 100149. https://doi.org/10.1016/j.obmed.2019.100149

Organization for Economic Cooperation and Development. (2016). *The economic consequences of outdoor air pollution*. https:

//www.oecd.org/environment/indicators-modelling-outlooks/Policy-Highlights-Economic-consequences-of-outdoor-air-pollution-web.pdf.

Parasin, N., Amnuaylojaroen, T., & Saokaew, S. (2021). Effect of Air Pollution on Obesity in Children: A Systematic Review and Meta-Analysis. *Children*, *8*(5), 327. https://doi.org/10.3390/children8050327

Roman-Viñas, B., Serra-Majem, L., Hagströmer, M., Ribas-Barba, L., Sjöström, M., & Segura-Cardona, R. (2010). International Physical Activity Questionnaire: Reliability and validity in a Spanish population. *European Journal of Sport Science*, *10*(5), 297-304. https://doi.org/10.1080/17461390903426667

Schane, R. E., Ling, P. M., & Glantz, S. A. (2010). Health Effects of Light and Intermittent Smoking: A Review. *Circulation*, *121*(13), 1518-1522. https://doi.org/10.1161/CIRCULATIONAHA.109.904235

Seo, M. Y., Kim, S.-H., & Park, M. J. (2020). Air pollution and childhood obesity. *Clinical and Experimental Pediatrics*, *63*(10), 382-388. https://doi.org/10.3345/cep.2020.00010

Sociedad Española de Nutrición Comunitaria. (2016). *Guías alimentarias para la población española*. https://www.nutricioncomunitaria.org/es/noticia-documento/43

Stival, C., Lugo, A., Odone, A., van den Brandt, P. A., Fernandez, E., Tigova, O., Soriano, J. B., López, M. J., Scaglioni, S., Gallus, S., & TackSHS Project Investigators. (2022). Prevalence and correlates of overweight and obesity in 12 European Countries in 2017-2018. *Obesity Facts*. https://doi.org/10.1159/000525792

Tainio, M., Jovanovic Andersen, Z., Nieuwenhuijsen, M. J., Hu, L., de Nazelle, A., An, R., Garcia, L. M. T., Goenka, S., Zapata-Diomedi, B., Bull, F., & Sá, T. H. de. (2021). Air pollution, physical activity and health: A mapping review of the evidence.

Environment International, *147*, 105954. https://doi.org/10.1016/j.envint.2020.105954

Tamayo-Ortiz, M., Téllez-Rojo, M. M., Rothenberg, S. J., Gutiérrez-Avila, I., Just, A. C., Kloog, I., Texcalac-Sangrador, J. L., Romero-Martinez, M., Bautista-Arredondo, L. F., Schwartz, J., Wright, R. O., & Riojas-Rodriguez, H. (2021). Exposure to PM2.5 and Obesity Prevalence in the Greater Mexico City Area. *International Journal of Environmental Research and Public Health*, *18*(5), 2301. https://doi.org/10.3390/ijerph18052301

Toledo-Corral, C. M., Alderete, T. L., Habre, R., Berhane, K., Lurmann, F. W., Weigensberg, M. J., Goran, M. I., & Gilliland, F. D. (2018). Effects of air pollution exposure on glucose metabolism in Los Angeles minority children: Effects of air pollution on glucose metabolism. *Pediatric Obesity*, *13*(1), 54-62. https://doi.org/10.1111/ijpo.12188

Tong, J., Ren, Y., Liu, F., Liang, F., Tang, X., Huang, D., An, X., & Liang, X. (2022). The Impact of PM2.5 on the Growth Curves of Children's Obesity Indexes: A Prospective Cohort Study. *Frontiers in Public Health*, *10*, 843622. https://doi.org/10.3389/fpubh.2022.843622

Torres-Carot, V., Suárez-González, A., & Lobato-Foulques, C. (2022). The energy balance hypothesis of obesity: Do the laws of thermodynamics explain excessive adiposity? *European Journal of Clinical Nutrition*. https://doi.org/10.1038/s41430-021-01064-4

Townshend, T., & Lake, A. (2017). Obesogenic environments: Current evidence of the built and food environments. *Perspectives in Public Health*, *137*(1), 38-44. https://doi.org/10.1177/1757913916679860

Vrijheid, M., Fossati, S., Maitre, L., Márquez, S., Roumeliotaki, T., Agier, L., Andrusaityte, S., Cadiou, S., Casas, M., de Castro, M., Dedele, A., Donaire-Gonzalez, D., Grazuleviciene, R., Haug, L. S., McEachan, R., Meltzer, H. M., Papadopouplou, E., Robinson, O., Sakhi, A. K., … Chatzi, L. (2020). Early-Life Environmental Exposures and Childhood Obesity: An Exposome-Wide Approach. *Environmental Health Perspectives*, *128*(6), 067009. https://doi.org/10.1289/EHP5975

Wilding, S., Ziauddeen, N., Smith, D., Roderick, P., Chase, D., & Alwan, N. A. (2020). Are environmental area characteristics at birth associated with overweight and obesity in school-aged children? Findings from the SLOPE (Studying Lifecourse Obesity PrEdictors) population-based cohort in the south of England. *BMC Medicine*, *18*(1), 43. https://doi.org/10.1186/s12916-020-01513-0

World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization. https://apps.who.int/iris/handle/10665/345329

Yan, W., Wang, X., Dong, T., Sun, M., Zhang, M., Fang, K., Chen, Y., Chen, R., Sun, Z., & Xia, Y. (2020). The impact of prenatal exposure to PM2.5 on childhood asthma and wheezing: A meta-analysis of observational studies. *Environmental Science and Pollution Research*, *27*(23), 29280-29290. https://doi.org/10.1007/s11356-020-09014-6

Tables

Table 1. Descriptive data of the analyzed sample (n=4378).

Variables	**Low $PM_{2.5}$** (1st tertile)	**Medium $PM_{2.5}$** (2nd tertile)	**High $PM_{2.5}$** (3rd tertile)	
	M (SD)/n (%)	*M (SD)/n (%)*	*M (SD)/n (%)*	*p*
Total, n (%)	1196 (27.3)	1809 (41.3)	1373 (31.4)	
Sociodemographic				
Age (years)	8.7 (3.7)	8.7 (3.7)	8.6 (3.7)	0.600
Age group				
Toddlers (2 years)	64 (5.4)	119 (6.6)	84 (6.1)	
Preschoolers (3-5 years)	229 (19.1)	309 (17.1)	269 (19.6)	**<0.001**
Children (6-12 years)	779 (65.1)	1210 (66.9)	890 (64.8)	
Adolescents (13-14 years)	124 (10.4)	171 (9.5)	130 (9.5)	
Sex				
Boys	598 (50.0)	984 (52.4)	688 (50.1)	0.310
Girls	598 (50.0)	861 (47.6)	685 (49.9)	
SES				
High SES	304 (25.4)	415 (22.9)	269 (19.5)	
Medium SES	397 (33.2)	642 (35.5)	456 (33.2)	**0.001**
Low SES	495 (41.4)	652 (41.6)	658 (47.2)	
Lifestyle				
Sleep duration (hours)	9.5 (1.2)	9.4 (1.2)	9.4 (1.1) †	**0.017**
Recreational ST (hours)	1.9 (1.1)	1.9 (1.2)	1.9 (1.2)	0.874
PA				
No exercise	181 (15.1)	300 (16.6)	278 (20.2)	
Occasional sport, or PA participation	294 (24.6)	434 (24.0)	333 (24.3)	**<0.001**
PA several times monthly	280 (23.4)	532 (29.4)	426 (31.0)	
Physical training or sports several times weekly	441 (36.9)	543 (30.0)	336 (24.5)	
S-HEI (score)	71.1 (8.4)	69.6 (8.8) †	70.0 (9.9) †	**<0.001**
Environmental				
Tobacco smoke exposure				
No exposure	1121 (93.7)	1704 (94.2)	1249 (91.0)	**0.009**
Exposure	75 (6.3)	105 (5.8)	124 (9.0)	
Air pollution				
$PM_{2.5}$ ($\mu g/m^3$)	10.13 (1.79)	12.45 (0.43) †	16.69 (2.75) †,‡	**<0.001**
Anthropometric data				
Weight (kg)	34.4 (15.6)	34.9 (15.7)	35.0 (16.0)	0.613
Height (cm)	134.4 (24.3)	133.9 (24.9)	133.8 (24.3)	0.782
BMI (kg/m^2)	18.0 (3.6)	18.5 (3.6) †	18.5 (3.9) †	**0.002**
BMI (z score) [a]	0.38 (1.43)	0.59 (1.44) †	0.56 (1.49) †,‡	**<0.001**
Excess weight (%) [b]	382 (31.9)	697 (38.5)	561 (40.9)	**<0.001**

Data are expressed as the mean (standard deviation) or numbers (percentages). BMI, body mass index; $PM_{2.5}$, particulate matter 2.5; S-HEI, Spanish Healthy Eating Index; SES, socioeconomic status; ST, screen time. [a] According to the International Obesity Task Force (Cole & Lobstein, 2012). [b] Excess weight computed as the sum of participants with overweight and obesity. † Statistically significant difference compared to the low $PM_{2.5}$; ‡ Statistically significant difference compared to the medium $PM_{2.5}$. Bold indicates a *p* value <0.05.

Table S1. Analyses of binary logistic regression between different particulate matter 2.5 established categories and excess weight adjusted for sociodemographic, lifestyle, and environmental covariates.

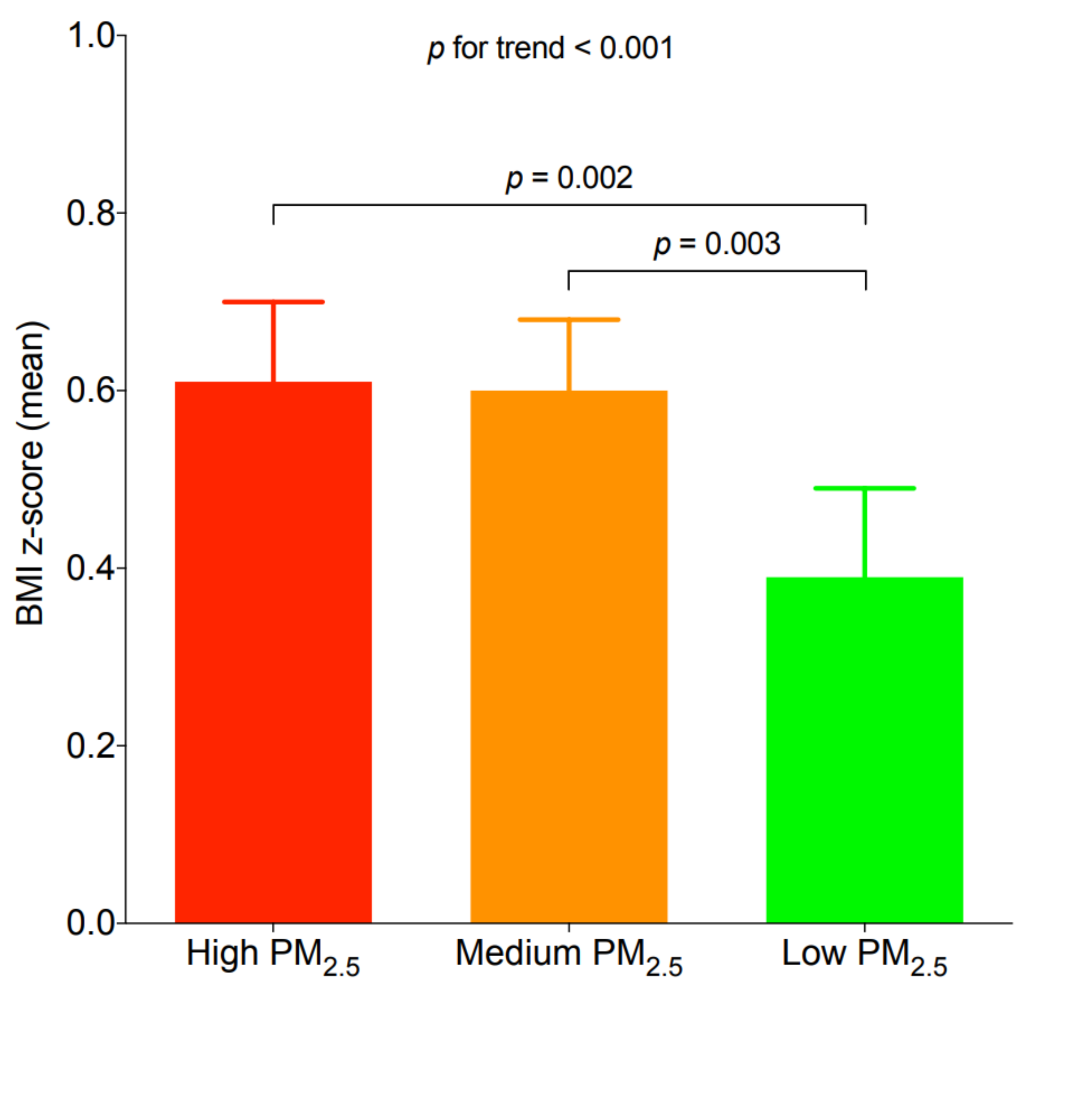
Potential predictors	Excess weight [a]											
	Model 0			Model 1			Model 2			Model 3		
	OR	*CI 95%*	*p*	*OR*	*CI 95%*	*p*	*OR*	*CI 95%*	*p*	*OR*	*CI 95%*	*p*
$PM_{2.5}$ category												
High $PM_{2.5}$	1.44	1.18-1.74	**<0.001**	1.37	1.13-1.66	**0.001**	1.35	1.11-1.64	**0.004**	1.35	1.11-1.64	**0.003**
Medium $PM_{2.5}$	1.25	1.04-1.50	**0.018**	1.24	1.02-1.49	**0.027**	1.23	1.02-1.49	**0.040**	1.23	1.02-1.49	**0.031**
Low $PM_{2.5}$ (Ref.)	1			1			1			1		
Covariates												
Age group												
Toddlers (2 years) (Ref.)	-	-	-	1			1			1		
Preschoolers (3-5 years)	-	-	-	1.52	1.03-2.24	**0.035**	1.39	0.93-2.05	0.106	1.39	0.93-2.06	**0.035**
Children (6-12 years)	-	-	-	1.63	1.13-2.33	**0.008**	1.34	0.89-1.97	0.149	1.34	0.90-1.99	**0.008**
Adolescents (13-14 years)	-	-	-	1.19	0.77-1.82	0.440	0.88	0.53-1.40	0.591	0.87	0.54-1.42	0.440
Sex (girls)												
Boys (Ref.)	-	-	-	1			1			1		
Girls	-	-	-	1.06	0.91-1.23	0.443	1.06	0.91-1.23	0.477	1.06	0.91-1.23	0.478
SES status												
High SES (Ref.)	-	-	-	1			1			1		
Medium SES	-	-	-	1.23	1.01-1.51	0.054	1.21	0.98-1.49	0.075	1.21	0.98-1.49	0.077
Low SES	-	-	-	1.92	1.58-2.34	**<0.001**	1.87	1.53-2.28	**<0.001**	1.85	1.52-2.27	**<0.001**
Sleep duration (per one hour)	-	-	-	-	-	-	0.88	0.82-0.95	**<0.001**	0.88	0.82-0.95	**<0.001**
Recreational ST (per one hour)	-	-	-	-	-	-	1.04	0.97-1.11	0.292	1.04	0.97-1.11	0.897
PA												
No exercise (Ref.)	-	-	-	-	-	-	1			1		
Occasional sport, or PA participation	-	-	-	-	-	-	1.03	0.86-1.39	0.808	1.03	0.81-1.32	0.453
PA several times per month	-	-	-	-	-	-	0.93	0.82-1.32	0.543	0.93	0.73-1.18	0.795
Physical training or sports several times per week	-	-	-	-	-	-	0.98	0.77-1.26	0.894	0.98	0.77-1.26	0.541
S-HEI (per one point)							1.00	0.99-1.01	0.559	1.00	0.99-1.01	0.479
Tobacco smoke exposure												
No exposition (Ref)	-	-	-	-	-	-	-	-	-	1		
Exposition	-	-	-	-	-	-	-	-	-	1.14	0.84-1.54	0.403

Model 0: crude; Model 1: adjusted for sociodemographic covariates (age group, sex, and socioeconomic status); Model 2: adjusted for Model 1 + lifestyle covariates (sleep duration, recreational screen time, physical activity, and diet quality); Model 3: adjusted for Model 2 + environmental covariates (tobacco smoke exposure). CI, confidence interval; OR, odds ratio; PA, physical activity; $PM_{2.5}$, particulate matter 2.5; S-HEI, Spanish Healthy Eating Index; SES, socioeconomic status; ST, screen time. [a] Following the International Obesity Task Force criteria (Cole & Lobstein, 2012). Bold indicates a *p* value <0.05.

Table S2. Analyses of binary logistic regression between particulate matter 2.5 and excess weight adjusted for sociodemographic, lifestyle, and environmental covariates.

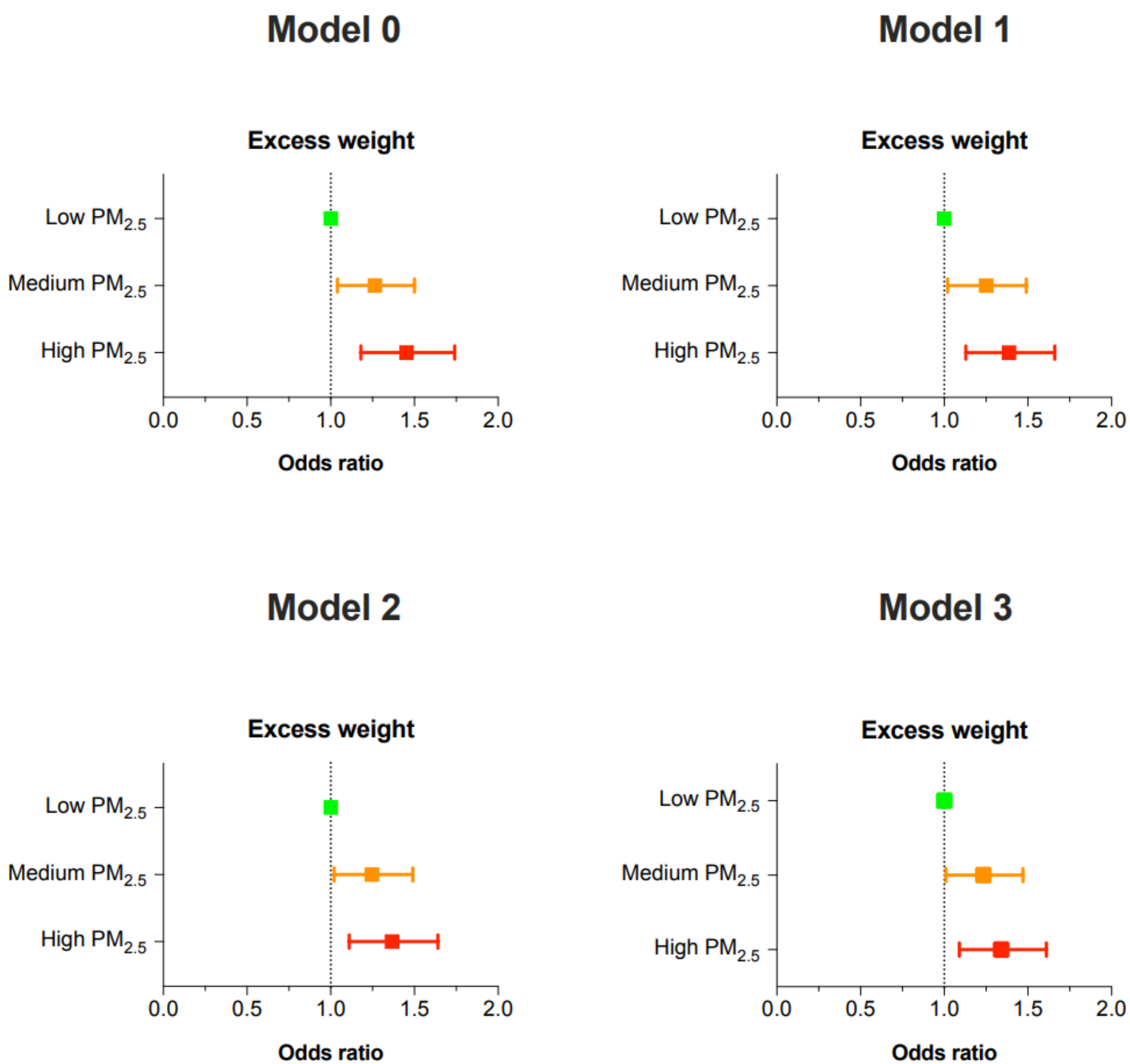
Potential predictors	**Excess weight [a]**											
	Model 0			**Model 1**			**Model 2**			**Model 3**		
	OR	*CI 95%*	*p*	*OR*	*CI 95%*	*p*	*OR*	*CI 95%*	*p*	*OR*	*CI 95%*	*p*
$PM_{2.5}$ (per one $\mu g/m^3$)	1.03	1.01-1.06	**0.004**	1.03	1.01-1.06	**0.009**	1.03	1.01-1.06	**0.007**	1.04	1.01-1.06	**0.008**
Covariates												
Age group												
Toddlers (2 years) (Ref.)	-	-	-	1			1			1		
Preschoolers (3-5 years)	-	-	-	1.51	1.02-2.22	**0.038**	1.37	0.92-2.04	0.122	1.37	0.92-2.04	0.123
Children (6-12 years)	-	-	-	1.62	1.13-2.32	**0.009**	1.32	0.89-1.96	0.173	1.32	0.89-1.96	0.171
Adolescents (13-14 years)	-	-	-	1.18	0.77-1.82	0.447	0.86	0.53-1.39	0.537	0.86	0.53-1.39	0.534
Sex (girls)												
Boys (Ref.)	-	-	-	1			1			1		
Girls	-	-	-	1.06	0.91-1.23	0.452	1.06	0.91-1.23	0.487	1.05	0.91-1.23	0.488
SES status												
High SES (Ref.)	-	-	-	1			1			1		
Medium SES	-	-	-	1.22	0.99-1.51	0.057	1.22	0.99-1.51	0.057	1.22	0.99-1.50	0.058
Low SES	-	-	-	1.89	1.55-2.31	**<0.001**	1.89	1.55-2.31	**<0.001**	1.88	1.54-2.30	**<0.001**
Sleep duration (per one hour)	-	-	-	-	-	-	0.88	0.82-0.95	**0.001**	0.88	0.82-0.95	**0.001**
Recreational ST (per one hour)	-	-	-	-	-	-	1.00	0.99-1.01	0.286	1.00	0.99-1.01	0.308
PA												
No exercise (Ref.)	-	-	-	-	-	-	1			1		
Occasional sport, or PA participation	-	-	-	-	-	-	1.04	0.82-1.33	0.737	1.04	0.82-1.33	0.727
PA several times per month	-	-	-	-	-	-	0.94	0.74-1.20	0.612	0.94	0.74-1.20	0.609
Physical training or sports several times per week	-	-	-	-	-	-	0.98	0.76-1.25	0.866	0.98	0.76-1.25	0.867
S-HEI (per one point)							1.00	0.99-1.01	0.457	1.00	0.99-1.01	0.524
Tobacco smoke exposure												
No exposition (Ref)	-	-	-	-	-	-	-	-	-	1		
Exposition	-	-	-	-	-	-	-	-	-	1.13	0.84-1.54	0.418

Model 0: crude; Model 1: adjusted for sociodemographic covariates (age group, sex, and socioeconomic status); Model 2: adjusted for Model 1 + lifestyle covariates (sleep duration, recreational screen time, physical activity, and diet quality); Model 3: adjusted for Model 2 + environmental covariates (tobacco smoke exposure). CI, confidence interval; OR, odds ratio; PA, physical activity; $PM_{2.5}$, particulate matter 2.5; S-HEI, Spanish Healthy Eating Index; SES, socioeconomic status; ST, screen time. [a] Following the International Obesity Task Force criteria (Cole & Lobstein, 2012). Bold indicates a *p* value <0.05.



p for trend < 0.001
p = 0.002
p = 0.003
BMI z-score (mean)
1.0
0.8
0.6
0.4
0.2
0.0
High PM2.5
Medium PM2.5
Low PM2.5

594


Model 0
Excess weight
Low PM2.5
Medium PM2.5
High PM2.5
0.0 0.5 1.0 1.5 2.0
Odds ratio
Model 1
Excess weight
Low PM2.5
Medium PM2.5
High PM2.5
0.0 0.5 1.0 1.5 2.0
Odds ratio
Model 2
Excess weight
Low PM2.5
Medium PM2.5
High PM2.5
0.0 0.5 1.0 1.5 2.0
Odds ratio
Model 3
Excess weight
Low PM2.5
Medium PM2.5
High PM2.5
0.0 0.5 1.0 1.5 2.0
Odds ratio