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Movement behaviours, air pollution and health in school-aged children: a cross-sectional study to guide the co-creation of healthier environments – the MOVE-AIR project

Clarice Martins,[1,2] João Cavaleiro Rufo,[2,3,4] Hélder Fonseca,[1,2] Ana Padrão,[1] Liliana C Baptista,[2,5] Maria Paula Santos,[1,2] Miguel Sousa ,[1] Rodrigo Zacca,[1,2,6,7] José Pedro Silva,[3] Ana Isabel Ribeiro [2,3,8]

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ABSTRACT

Introduction The MOVE-AIR study was designed to explore the moderating role of movement behaviours on the association between air pollutants and health outcomes in Portuguese children. Secondarily, it aims to characterise the settings (both indoor and outdoor) where children are exposed to air pollutants and to co-create solutions with participants to mitigate the exposure to air pollutants in children's daily life. This study aims to describe the MOVE-AIR study protocol in detail.

Methods and analysis Data from 52 primary school children aged 9–11 years will be assessed for indoor and outdoor air pollutants (particulate matter (PM)$_{2.5}$ and PM$_{10,}$ and carbon dioxide), geo-tracked for distinct settings (ie, home/school, indoor/outdoor) along the day, through an optical monitoring sensor with Global Positioning System incorporated. Health-related biological outcomes, such as interleukin-6, tumour necrosis factor alpha and oxidative parameters, including total antioxidant status and total oxidant status, will be evaluated and the Oxidative Stress Index will be calculated. Children's cardiopulmonary fitness will be assessed through the shuttle run test, and movement behaviours will be evaluated through accelerometers (wGT3X). Children's sex, age and parental socioeconomic status will be provided by parents through a questionnaire. The influence of movement behaviours in the link between pollution and health will be analysed through moderating regression models using process for SPSS R software (V.30.0.0). A subsample of class teachers, school leaders, parents and children will be invited to a co-creation process to create solutions to mitigate their daily exposure to air pollutants. The results will contribute to further understanding the moderating role of movement behaviours in the association between air pollution and health, adding a biological layer to the mechanistic links underlying these potential relationships that have not been explored in this target population. Finally, enhancing our comprehension of the living environments and contexts where children are more exposed to air pollution can help to cooperatively create solutions to mitigate their daily exposure to those harmful pollutants.

Ethics and dissemination Ethical approval was granted by the Ethics Committee of the Faculty of Sports from the University of Porto (CEFADE 32–2023), and the study complies with the European Union (EU) General Data Protection Regulation under the supervision of the Data Protection Office of the Institute of Public Health, University of Porto (ISPUP).

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The proposed real-time, individual-level exposure assessment of air pollution (particulate matter (PM)$_{2.5}$, PM$_{10}$, carbon dioxide) using portable monitors, combined with geolocation and accelerometry, will allow a complete estimation on what, where and how children are exposed to air pollutants.

⇒ The assessment of health outcomes is a clear strength of our protocol, using a naturalistic, school-based setting for data collection, which enhances ecological validity and minimise disruption to children's routines.

⇒ The cross-sectional study design of the MOVE-AIR project will limit our ability to establish causal relationships, and the small sample size determined due to budget constraints may limit generalisability.

INTRODUCTION

Clean air is essential to human health whereas ambient air pollution is a critical environmental factor of mortality and morbidity worldwide,[1] responsible for 4.2 million deaths in 2016.[2] Exposure to air pollution is associated with a wide range of health harms, including respiratory and cardiovascular diseases,[3] but it is also a significant risk to children's health. Their developing immune system and lungs, associated with their relatively high inhalation rate,[4] put children at risk of detrimental clinical consequences, such as pulmonary and systemic inflammation,

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For numbered affiliations see end of article.

Correspondence to
Mr Miguel Sousa;
up202105205@up.pt

increased oxidative stress,[5] premature death and delayed cognitive development.[6]

Physical activity (PA) has been shown to enhance cardiopulmonary fitness, vascular and endothelial activity and resistance to infection.[7 8] Besides PA, other co-dependent movement behaviours, namely sleep and sedentary behaviour,[9 10] which coexist on a continuum that interacts within a 24-hour period, seem intrinsically related to outdoor air pollutants and might cooperatively impact children's health. Optimal movement behaviours, including high PA, sufficient sleep and minimal sedentary behaviour, lead to better health outcomes among children and youth.[11]

Results on the effects of exercising in polluted environments are conflicting. In one hand, it may increase the risk of inhalation of pollution particles (eg, airborne particulate matter <2.5 µm ($PM_{2.5}$) and <10 µm (PM_{10})), increasing respiratory rate and reducing nasal resistance.[12–14] On the other hand, a cohort Danish study with the elderly showed that exposure to high levels of traffic-related air pollution indicated beneficial effects of PA on mortality.[15] Also, high concentrations of outdoor air pollutants have been positively linked to poor sleep quality, though findings are inconsistent for sleep duration and sedentary behaviour.[9] This is critical because poor sleep has also become an important public health concern, affecting as many as one-third of all children.[16] In 2021, Kim *et al*[17] conducted a review on the impact of outdoor air pollution on movement behaviours, revealing two conflicting patterns: one depicting an association between reduced PA, increased sedentary behaviour and poorer sleep; and the other suggesting no association between air pollutants and movement behaviours. Thus, evidence on the topic is still lacking. Specifically, it remains uncertain whether children exposed to air pollution experience adverse health effects primarily due to their suboptimal movement behaviours or the direct impact of air pollution. Additionally, it is unclear if children with healthy movement behaviours are less susceptible to the detrimental effects of air pollution.

In parallel, indoor air pollution has traditionally received less attention than outdoor pollution. Studies exploring the association between indoor air pollution, children's movement behaviours and health outcomes are scarce, even though indoor air pollution levels are typically two times as high,[18] and between 23% and 35% of a school-aged child's day is spent in indoor school environments.[19] This high-risk period includes morning hours when the highest peak in ambient air pollution is commonly noted.[20] This is important because the exposure to contaminants in such school indoor environments has a great influence on the performance and attendance of students at schools.[21]

Traditionally, air quality has been monitored using stationary monitoring stations, typically positioned at urban locations or near traffic hotspots.[22] While these stations are effective for tracking overall trends and meso-level regional differences, their high installation and maintenance costs restrict data collection to a limited number of locations making them not useful for individual-level studies.[23] Additionally, fixed-site measurements may not accurately reflect the air pollution dynamically experienced by individuals, due to the spatial and temporal variability of air pollution.[24] Note that air pollution varies greatly over small distances, and the careful consideration of areal units to assign exposure is essential to avoid exposure misclassification.[25] More recently, a study conducted in London[26] assessed children's exposure to air pollutants using backpacks with built-in air quality sensors. The authors identified that children who walked to and from school through busy main roads were exposed to 33% higher levels of air pollution than those who travelled through back streets, though no information regarding movement behaviours has been monitored.

Concerning the abovementioned, the rationale for the MOVE-AIR study is grounded in the concern about how movement behaviours interact with exposure to air pollutants and children's health. While substantial evidence links air pollution to cardiopulmonary and metabolic risks, less is known about how PA, sedentary behaviour and sleep may mitigate or exacerbate these associations, particularly in school-aged children. The core research question driving the MOVE-AIR study is: do movement behaviours moderate the association between exposure to real-time and individually measured air pollutants and health outcomes in children? To answer this main question, the MOVE-AIR project was designed to explore the moderating role of movement behaviours on the association between air pollutants and health outcomes in Portuguese children. Secondarily, the project aims to characterise the settings (both indoor and outdoor) where children are exposed to higher and lower levels of air pollutants; and to co-create solutions with participants to mitigate the exposure to air pollutants in children's daily life. We hypothesise that: (1) children exposed to settings with greater air pollutants concentration will have increased inflammatory markers, oxidative stress and lower cardiopulmonary fitness; (2) children less exposed to ambient air pollution will have healthier movement behaviours profile (high PA, sufficient sleep and minimal sedentary behaviour) and thereby lower inflammatory markers, oxidative stress and better cardiopulmonary fitness; and (3) the adverse impact of air pollutants on children's health is attenuated or absent for those children that are moderately active, with greater sleep duration and quality and less sedentary. Furthermore, the co-creation process will contribute to increasing participants' awareness and understanding of the topic and their health consequences. The current protocol study aims to provide a detailed description of the MOVE-AIR protocol.

METHODS

This cross-sectional project was designed to explore the moderating role of movement behaviours on the

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association between air pollution and health outcomes of primary school-children. A collaboration with the Northern Regional Educational Board and with physical education (PE) teachers from the selected primary schools will be established to collect the primary data within the school context. We will use the logistic and material resources from the CIAFEL (Centro de Investigação em Actividade Física, Saúde e Lazer) and the EPIUnit (Unidade de Investigação em Epidemiologia) research centres to optimise financial and human resources for the project.

Setting and participants

The project will be conducted in the Porto Metropolitan Area. Data will be collected from May to June 2025. Three primary schools in the urban parishes of Matosinhos municipality, and three primary schools in the suburban parishes of Valongo municipality will be conveniently invited to be part of the study. Schools in urban and suburban areas were pre-screened to ensure enough variability in the air quality parameters to be assessed. For instance, in urban areas, there are schools in the city centre, close to the beach and in the Porto airport zone, while in the suburban area, the schools are in agricultural areas (figure 1).

Sample sizes of studies that used individual sensors to capture air pollutants in children vary substantially[26–30] (ie, 40–258), though no information regarding biological health outcomes or acceleration data has been combined. The common rate loss in accelerometer data with school children is 20%, due to the complexity in combining valid PA and sleep measured hours in such ages. Also, the parents' consent to collect saliva sample is another critical point in the current study. These difficulties are particularly enhanced due to the assessments in two distinct home contexts (urban and suburban settings). Thus, the minimum sample size required for this project was estimated using typical effect size estimations of 0.36 for the health outcomes to be measured, considering an alpha error of 0.05 and 20% increase/decrease due to exposure. Based on these criteria, and the analytical approaches to be used, the minimum sample size of 47 children (9–11 years old) was estimated to be recruited. To account for anticipated refusals and drop-outs during the assessment period, an additional 20% was added, bringing the total number of children to be recruited to 52. Typical neurodeveloped children who agree to participate and whose legal guardians give consent will be eligible for the study.

Since schools have at least one class for each of the third and fourth level of schooling (approximately 20–25 children per school), six schools (three in each living context) will be invited to participate in the project to recruit the number of children that we need to assess, since this number is expected to be lower in suburban areas due to the lower number of inhabitants of the selected suburban context.

We will obtain all pedagogical and institutional approvals in each school. The pre-screened schools will be contacted by a research team member to ensure they meet our inclusion/exclusion criteria (ie, agree in participating; provide a room for biological outcomes' assessments; provide a PE class for cardiorespiratory fitness assessment). If a pre-screened school does not attend the eligible criteria, other school in the same area will be selected.

Assessments

All participating children will undergo assessments involving various exposure variables, outcome variables, movement behaviours and additional covariates. Regarding exposure variables, indoor and outdoor air pollutants, specifically $PM_{2.5}$, PM_{10} and carbon dioxide (CO_2), will be measured. The settings (indoor vs outdoor) and the time children spend in each environment throughout the day will be tracked using a Global Positioning System (GPS). Health outcomes will include the evaluation of salivary inflammatory biomarkers, such as interleukin-6 (IL-6) and tumour necrosis factor alpha (TNF-α), as well as oxidative stress parameters like total antioxidant status (TAS) and total oxidant status (TOS). From these measurements, the Oxidative Stress Index (OSI) will be calculated. Additionally, cardiopulmonary fitness will be assessed through a cardiorespiratory field test. Movement behaviours, including PA, sedentary behaviour and sleep duration, will be monitored using accelerometers. Information regarding children's sex, age and parental socioeconomic status will be collected through parent-provided questionnaires. Below, we describe these assessments in more detail.

Biomarkers

Children will be directed individually to a private school's room to assess biological health outcomes. They will receive Salivette tubes (SARS51.1534, SARSTEDT, DE) to collect a saliva sample between 08:00 and 10:00, at least 60 min after liquid or solid food intake or tooth brushing. The collected material will be stored in ice-cold conditions and immediately transported to the Biochemistry laboratory of the Faculty of Sport. After swab centrifugation, saliva will be collected, aliquoted in microtubes and stored at −80°C for later assessment of pro-inflammatory markers and oxidative stress parameters. Salivary TAS is usually used to measure the overall antioxidant level, and TOS is usually used to estimate the overall oxidant level. These parameters will be measured by commercially available kits (EBC-K801-M and E-BC-K802-M, respectively; Elabscience, USA). The ratio of TOS to TAS will be used to calculate the OSI, an indicator of the degree of oxidative stress. Salivary pro-inflammatory biomarkers IL-6 and TNF-α will be quantified by commercially available ELISA kits, according to the company instructions (#43057 and #430207, respectively, BioLegend, USA). Children with evident periodontal disease (eg, periodontitis) or dental plaque will be excluded from the saliva collection process to avoid bias.[31]

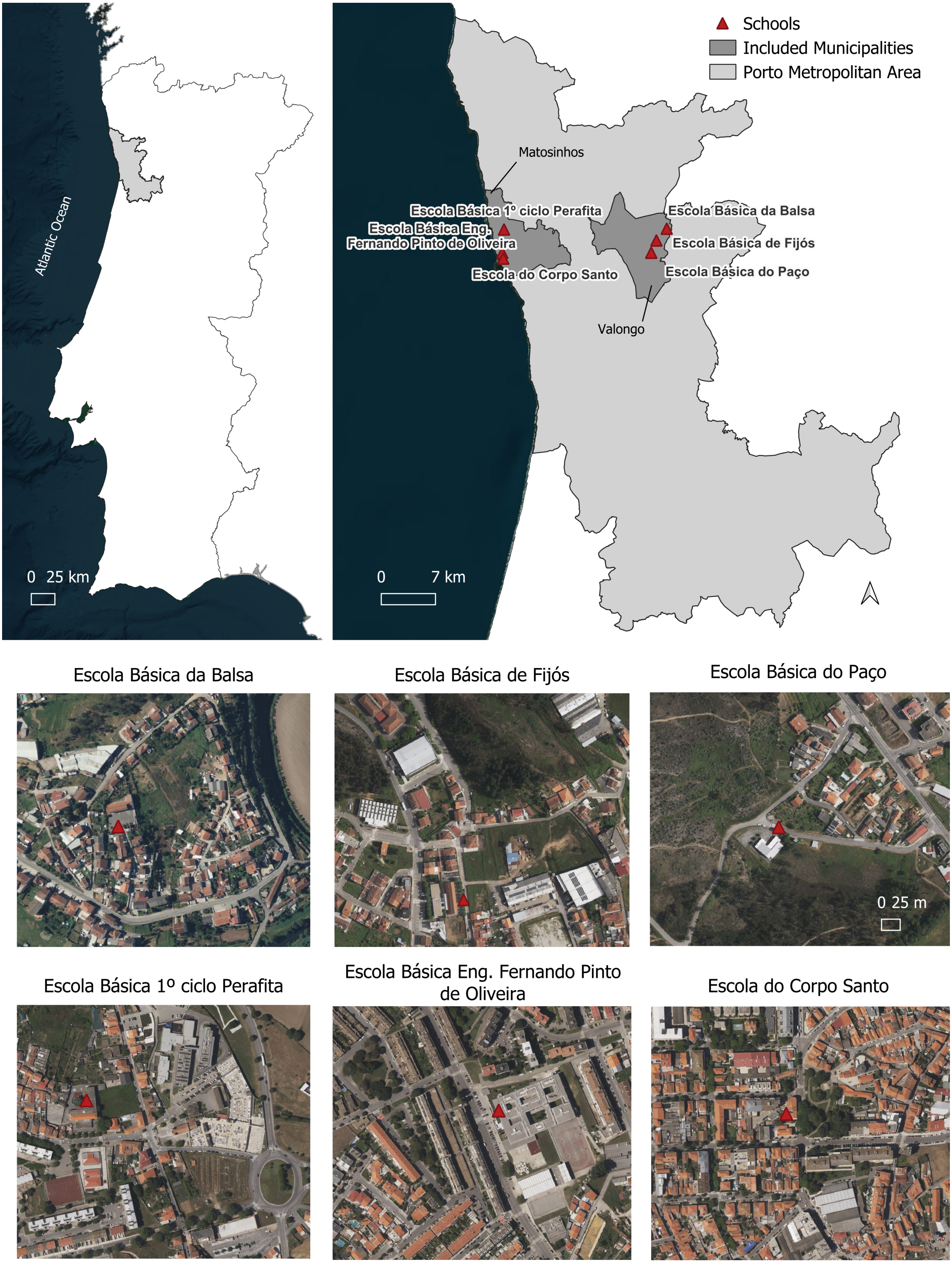

Figure 1 Geographical location of the schools.

Cardiopulmonary fitness

Children's cardiopulmonary fitness will be assessed using the reliable, valid and feasible cardiorespiratory fitness test metres Shuttle-Run Test (20-mSRT),[32] based on the prototype of Léger *et al*,[33] to predict maximal aerobic power (ie, the maximal oxygen uptake – $\dot{V}O_{2max}$; mL/kg/min) from maximal running speed, defined as the maximal aerobic speed. This test will be performed by running continuously between two points at a distance of 20 m. The time of change from one point to another will be determined by audio feedback via a characteristic 'beep' sound. Children will run to an audible signal pace at an initial speed of 8.5 km/hour and speed will be increased by 0.25 km/hour every minute. After each minute, a vibrating sound will indicate an increase in speed level (level change). This test terminates when the participant: (1) is unable to continue the test because of fatigue or other symptoms (voluntary withdrawal), or (2) fails to reach the marker on time for three times.

Movement behaviours: physical activity, sedentary behaviour and sleep

Participants will wear tri-axial accelerometers ActiGraph wGT3X on their left hip for 24 hours per day, over seven consecutive days. The devices will be initialised to record at 90 Hz and the subsequent data will be downloaded using ActiLife (V.6.13.4). The raw data files (gt3x format) will be processed in R using package GGIR V.2.8–2. The raw triaxial accelerometer signals will be converted to one omnidirectional measure of body acceleration (Euclidean Norm Minus-One; ENMO) expressed in milligravitational units (mg).[34] For this, the vector magnitude will be taken from the three axes and then subtracted by the value of gravity (g) as in $(x^2 + y^2 + z^2)$ ½ – 1, after which, negative values will be rounded up to zero, referred to ENMO. Data will be further reduced by calculating the average values per 1 s epoch. Then, we will calculate the average of these 1 s epoch values over the seven monitored days to represent the average acceleration to be included in the statistical analyses. Signal processing will be done offline in R (http://cran.r-project.org/). The resulting values will be expressed in gravity-based acceleration units (g), where g=9.81 m/s^2. Children's specific hip ENMO cut-points of 48 mg,[35] 201 mg and 707 mg[36] will define the estimated upper threshold of sedentary time and lower threshold of light, moderate and vigorous PA, respectively. Sleep duration will be estimated using a polysomnography-validated accelerometer algorithm[37] valid for children's use in the hip, based on the distribution of change in the z-angle (ie, corresponding to the axis positioned perpendicular to the skin surface). All the children will receive the accelerometer diary with instructions, which will be completed by their parents. Parents will receive a daily message via mobile to remember about the use of the device and the completion of the diary.

Air pollutants and Global Positioning System

Children will use optical sensors to continuously assess PM_{10} and $PM_{2.5}$. CO_2 will be measured by non-dispersive infrared sensors, following national regulations for resolution and maximum admissible errors. Due to financial and technical constraints, we chose to limit the selected pollutants that will be directly measured based on those dictated for mandatory indoor air quality assessment in public buildings, according to Portuguese law. Nevertheless, ambient NO_2 exposure will be assessed by cross-referencing NO_2 concentrations from satellite imagery and the child's geolocation. The same approach will be applied to SO_2. Black carbon concentrations (both indoor and outdoor) will be estimated based on $PM_{2.5}$ concentrations, according to the linear regression models fitted by Wang *et al*.[38]

The settings (indoor/outdoor) where children spend their daily time will be tracked using a GPS. Ambient temperature and relative humidity will also be measured. Due to battery life constraints, air pollutants will be measured for 48 hours, comprising two representative weekdays (between Monday and Wednesday). During this period, the sensors will be used at all times, precisely tracking air quality and position values at every minute.

The selection of sensors for air quality pollutants was based on the following criteria: the existence of validation data published in peer-reviewed journals and meeting the specifications presented in Despacho 1618/22 of 9 February[39] (table 1).

The MH-Z19B non-dispersive infrared CO_2 sensor was selected to integrate the system,[40] while the NOVA SDS011 optical dispersion sensor was used to measure

Table 1 Requirements for indoor air quality measurement instruments, according to Portuguese Legislation—in Despacho 1618/22 of 9 February

Parameter	Reference method	Equivalent methods	Max admissible error	Resolution
CO_2	Non-dispersive infrared sensors	Electrochemical sensors Fourier transform infrared spectroscopy Photoacoustic sensor	50 ppm or 10%, whichever greater	1 ppm
PM_{10} and $PM_{2.5}$	Gravimetry	Laser or UV-based optical dispersion Beta ray absorption sensors Tapered element oscillating microbalances Piezoelectric resonance	10 µg/m^3 or 10%, whichever greater	1 µg/m^3

CO_2, carbon dioxide; PM, particulate matter; ppm, parts per million; UV, ultraviolet.

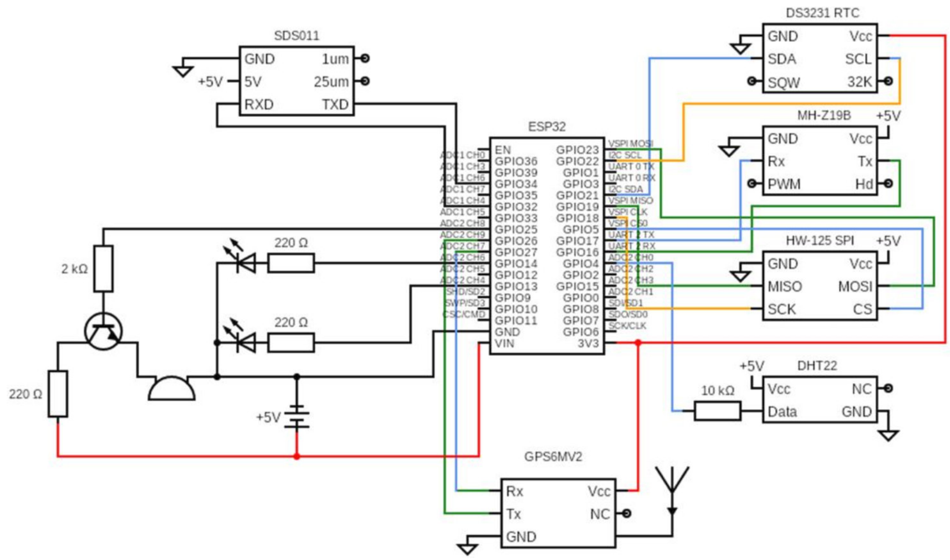

Figure 2 System circuit diagram of the MIDAS system and its multiple components: DHT22 (digital temperature and humidity sensor); DS3231 RTC (real-time clock); ESP32 microcontroller (Espressif Systems); GPS6MV2 (NEO-6MV2 Global Positioning System module); HW-125 SPI (microSD card reader using Serial Peripheral Interface); MH-Z19B (nondispersive infrared CO_2 sensor); and SDS011 (Nova SDS011 optical dust sensor for $PM_{2.5}$ and PM_{10}). Standard communication protocols and signals are indicated: CS (chip select), MISO (master in slave out), MOSI (master out slave in), NC (not connected), PWM (pulse width modulation), Rx (receive), SCK (serial clock), SCL (serial clock), SDA (serial data), SQW (square wave output), Tx (transmit), VCC (supply voltage), VIN (voltage input) and GND (ground).

PM_{10} and $PM_{2.5}$.[41] The DHT22 sensor was used to measure ambient temperature and relative humidity.[42] The NEO6MV2 module was used to track geolocation as latitude and longitude. An HW-125 SPI reader with a 16GB microSD card was used for local data storage. A DS3231 real-time clock (RTC) equipped with a 3 V emergency battery was used to track time. The inclusion of the RTC over GPS time was to avoid timestamp data losses due to eventual signal loss. The system was continuously supplied with 5 volts of direct current (V DC) through a commercially available external power bank (BI-B61). The system, which we named as MIDAS (figure 2), was controlled by an ESP32 microcontroller and the firmware was programmed in C++, using Arduino IDE. The ESP32 was chosen due to being low-cost, having integrated Bluetooth and showing high overall performance with low energy expenditure. MIDAS was programmed to take a measure of each parameter every minute, including date, time, temperature (°C), relative humidity (%), CO_2 (parts per million (ppm)), PM_{10} and $PM_{2.5}$ (µg/m^3) and latitude and longitude (°). In order to improve precision, particulate matter measurements were based on the average count of particles performed in the last 30s, calculated by the SDS011, rather than the instantaneous count.[41]

The sensors were installed into a separate case positioned in the backpack strap to capture readings close to the children's breathing area.

Data collection protocol

The research team will be in each school for 1month. This period was established to guarantee 2weeks of assessments for each class, due to the number of available devices to assess at least 10 children in each school. The class will perform the FitnessGram test, and each child will receive an accelerometer to be used for seven consecutive days, and a backpack containing the optical air quality monitoring system and GPS, to be used for two cycles of 24 hours (from Monday to Wednesday) and will be instructed on the correct way to use them. In that day, all the children will be provided with the parent's questionnaire to collect socio-demographic and home information (ie, type of house, number of people living in the same house, smokers in the house, heating source) and an accelerometer diary, along with clear instructions for completion. At the beginning of the second week, children will return the devices, the questionnaire and the diary and will carry out the Salivette assessment. The entire assessment protocol will last 7days for each class. In the subsequent week, another class will be assessed.

Data processing and statistical analysis

We will synchronise location and accelerometer data. The GPS and accelerometer data will be matched by date and time using existing software to obtain a dataset where for each recorded GPS point there is a measure of activity. The location-based categorisation of the matched data points will be operationalised by conducting geographical information system, ArcGIS Pro V.3.1 (ESRI, Redlands, California, USA). Each participant's data points will be imported into ArcGIS Pro. Participant's home and school will be geocoded and also imported into ArcGIS Pro. Participant's data points will then be overlaid with home and school locations, as well as cartography depicting administrative/census boundaries, land uses, green space/vegetation levels, proximity to roads and industry and other geographical features. This will allow us to descriptively characterise children's activity spaces in terms of setting (home and school, outdoor and indoor) and in terms of built, biophysical and social characteristics and to identify hotspots of high and low air pollution exposure.

Markers of inflammation (IL-6, TNF-α) and oxidative stress (TAS, TOS and OSI) will be operationalised in isolation, and correlations will be explored with other relevant variables such as exposure to ambient pollutants and PA volume and intensity metrics.

Health-related outcomes will be operationalised according to their nature. Cardiopulmonary fitness will be computed as the number of completed laps and maximal oxygen consumption (VO_2max) will be estimated according to the following equation (equation 1):

$$VO_2\,max = 31.025 + 3.238(speed,\ km/\ hour) - 3.248(age,\ years) + 0.1536(age \times speed) \quad (1)$$

Results of the shuttle run test will be qualitatively interpreted according to normative data provided in Tomkinson *et al*.[43]

Descriptive statistics such as the mean and SD, or median and IQR, will be used to summarise participant characteristics, movement behaviour, indoor and outdoor air pollution exposure levels (PM_{10}, $PM_{2.5}$, CO_2) and health outcomes. Data completeness and variability will guide subsequent modelling steps.

Air pollution exposure will be characterised using individual-level, real-time measurements of PM_{10}, $PM_{2.5}$ and CO_2, recorded in both indoor and outdoor environments. These pollutants will be treated as continuous variables and separately inserted in the models. Collinearity will be assessed using variance inflation factors, and if necessary, individual models for each pollutant will be constructed. Time-aligned exposure values will be averaged over valid measurement days and linked to individual behavioural and health outcome data.

Time-use data for PA, sedentary behaviour and sleep will be analysed using compositional data analysis (CoDA) due to their constrained 24-hour structure. Isometric log-ratio (ilr) transformations will be applied to construct valid predictors for regression models. Simplified ilr balances will be used to minimise overfitting given the sample size.

To explore whether movement behaviours moderate the association of air pollution on child health outcomes, we will use the PROCESS macro (ie, Models 1, 2 or 3 and its variations) with 1000 bootstrapped samples. This will estimate direct and interaction effects with bias-corrected CIs. Separate regression models will be constructed for each health outcome to be assessed, with one of the air pollutants (PM_{10}, $PM_{2.5}$, CO_2) as predictors, movement behaviours composition (ilr-transformed) as moderator and socio-demographic factors as covariates. Outcome-specific assumptions and diagnostics will be verified for each exploratory model. Statistical analyses will be performed using SPSS software (V.29.0.2.0), or R software (V.4.2.0, http://www.R-project.org, The R Foundation).

Although children are nested within schools and have multiple exposure measurements, the current sample size is insufficient for multilevel modelling. Instead, school will be included as a fixed-effect covariate, and air pollutants data will be contextually averaged (eg, indoor and outdoor).

Co-creation process

Based on their availability and interest to participate, a subsample of children most exposed to air pollution, plus class teachers, school leaders and parents will be invited to a participatory three-stage co-creation process, that will be facilitated by the research team. The goal of this process phase is to define solutions to mitigate the exposure of children to air pollutants in their daily lives. The stages will be aligned with the Double Diamond Design Approach (DDDA) by employing divergent and convergent thinking processes, which reflects how the specialists will discover, define, develop and deliver solutions to the 'problem', and how best to facilitate real-world implementation.[44] The DDDA is a well-regarded approach within design thinking and has been used in other co-creation research involving children.[45] The process will also observe the four principles of co-creation advanced by Leask and colleagues:[46] planning, conducting, evaluating and reporting.

Prospective participants will be invited to a session where members of the research team will present the co-creation process, including its goals, its different stages and methods and the role that both participants and researchers will have. Formal informed consent will be requested from participants willing to accept (in the case of children, consent will be requested both to the children and their legal guardians). The first stage of the co-creation process will consist of another session where researchers will share scientific evidence about the health impacts of air pollutants on children's health. This step will integrate the findings of the previous phase of the project in the co-creation process, and is consistent with the idea that participants have the right to receive information about the evidence base for the health issue being targeted, in order to inform their decisions. Stage two will consist of a participative workshop. Adult stakeholders (class teachers, school leaders and parents) will be divided into smaller groups, which will then engage in various activities in order to develop individual and place level solutions to mitigate the exposure to air pollutants in children's daily lives. Each group will be engaged in a brainstorming session, generating ideas about the mitigation of exposure to air pollutants in children's daily lives, corresponding to the 'discover' phase of the DDDA. This will be followed by the 'define' phase: the generated ideas will then be discussed, refined and further developed into proposed solutions. By the end of the session, each group will present its solutions and participants will vote on the most relevant ones to be included in the proposal. PA, epidemiology, health geography and sociology specialists who conduct the workshop will integrate existing research evidence using creative methods (eg, post-it note tasks, worksheets and drawings) to facilitate the group's discussion. To engage the children in the process, without them feeling inhibited in expressing their thoughts in the presence of adults, stage two consists of a similar workshop process with a children's group. Stage three, the 'develop' phase, consists of a meeting with the whole group to present the solutions that were developed and selected on the two previous co-creation workshops, to hear feedback from all participants and structure a proposal to be published and discussed with decision-makers and the schools involved (the final 'deliver' phase of the DDDA). Finally, at the end of the session, participants will complete an evaluation questionnaire of the co-creation process. Data collection tools including audio records, observation notes, participant worksheets and drawings will be used with the intention to illuminate discussion points and allow the participants' voices to be represented.

Data collected from the co-creation process will be subjected to an inductive thematic analysis, following the Braun and Clarke reflexive thematic analysis approach,[47 48] applied to qualitative data from workshops and interviews, while acceptability and feasibility will be assessed through structured feedback questionnaires and pre/post descriptive comparisons of environmental and behavioural indicators. Analysis will account for each school setting using NVivo V.14.0.

Ethics and dissemination

MOVE-AIR will follow all the ethical aspects related to research with human beings and vulnerable populations and was approved by the Ethics Committee of the Faculty of Sport University of Porto (CEFADE 32–2023). The study follows the European Union (EU) General Data Protection Regulation under the close supervision of the Data Protection Office of the Institute of Public Health from the University of Porto (ISPUP).

Participants and their legal guardians will be invited for voluntary participation. Given the participants' age, in addition to their assent, written consent will be asked of their guardians, approving the involvement in data collection, storage and use of the information for research purposes. Risks caused by the cardiorespiratory fitness assessment are of minor impact and similar to those in PE classes and school breaks (eg, falls, sprains). We will minimise it by close interaction with the educators and including only small groups (one class per session) for assessment. Although the integration of GPS technology in tracking children may raise ethical concerns related to children's privacy, we will develop a robust consent mechanism involving parents, children and the school, to ensure transparent communication on the purposes and security of the assessed information, as well as the empowering of families and schools with the right to choose how and when to use the device. We will use devices purchased specifically for this purpose and not mobile applications, so the data collected will be maintained offline and available only to the research team. All project-specific documents (except signed consent) will be stored securely in confidential conditions, and the participant will be referred to by an anonymous identification code, not the name or other trackable information. A protected cloud-based platform will be designed and open to the research team, to centralise data into a common repository. Data will be made available just to members of the MOVE-AIR project. Once data analysis is complete, data will be kept for 3 years after the project is complete, and then will be destroyed following data destruction standard guidelines.[49]

All the participants and legal guardians will receive individual reports, and the schools will receive a general anonymous report. The project's plan for results dissemination includes both scientific dissemination and science outreach and translation activities to achieve distinct interested groups in a way that all may benefit from the results. Scientific dissemination will be based on publications and presentation of the results at conferences. Along the assessments, the research team will prepare individual reports, translating the results into an easily understandable language to participants, parents and school staff. Furthermore, we will communicate research evidence in a way that is meaningful to decision-makers and the general population. This will be accomplished through the creation of information factsheets and infographics summarising the most practically impactful project results; television and radio interviews and social media; press releases of major project results; and open-access publications.

DISCUSSION

The MOVE-AIR project addresses the intersections between air pollution, movement behaviours and health outcomes in children. This research is particularly relevant given the important implications of air quality on public health and the unique vulnerabilities of the paediatric population.

Understanding the impact of air pollution on children's health is critical because children are more susceptible to pollutants due to their higher respiration rates and ongoing development.[4 5] The hypothesis that children with healthier movement behaviours (ie, higher PA, adequate sleep and lower sedentary time) may experience reduced adverse effects from air pollution is both innovative and plausible. Indeed, previous studies have suggested that PA can enhance cardiovascular and respiratory health, potentially mitigating some harmful effects of pollution.[13 14] Conversely, high pollution levels could impair these benefits by aggravating respiratory and cardiovascular issues. Thus, a nuanced understanding of how movement behaviours interact with pollution exposure is of major public health relevance.

Considering that children are especially susceptible to air pollution, it is critical to understand how movement behaviours influence the association between air pollution and children's health, especially because most children live in urban environments characterised by elevated levels of air pollution.[50] This project could inform public policies on health, urban planning and transportation by reducing health risks for children, promoting green spaces, supporting active commuting and implementing traffic regulations. The co-creation process and citizen science approach will generate feasible strategies to guide targeted public policies.

Moreover, the MOVE-AIR project is timely and aligns with global and national health goals, including the United Nations' Sustainable Development Goals 3 ('Good health and well-being') and 11 ('Sustainable cities and communities'), of the United Nations, with the Global Action Plan on Physical Activity 2018–2030 and with The Portuguese National Strategic Plan for the Promotion of Physical Activity, Health and Well-Being - 2016–2025.

The project also addresses the often-overlooked aspect of indoor air quality. Given that children spend significant time indoors at schools and homes, understanding how indoor air pollutants contribute to health outcomes, alongside outdoor pollution, is essential. Previous studies have indicated that indoor pollution can be significantly higher than outdoor levels,[18] yet there is limited research on its impact on children's health in conjunction with movement behaviours. By exploring both indoor and outdoor environments, the MOVE-AIR project aims to provide a comprehensive view of pollution exposure and its health implications.

An important strength of the MOVE-AIR project is its emphasis on co-creation and community involvement. Engaging children, parents, teachers and school leaders in the research process not only enhances the study's relevance and applicability but also ensures that the solutions developed are practical and grounded in real-world experiences. This participatory approach may lead to more effective and widely accepted interventions, thereby translating research findings into tangible improvements in public health.

Moreover, while the MOVE-AIR project collects sensitive spatial data, the research team will adhere to GDPR regulations and implement robust geoprivacy-preserving strategies to safeguard participants' privacy.[51] This includes using non-commercial, project-specific wearable devices designed explicitly for the study. In fact, a significant innovation step of the project is the development of the MIDAS system, a low-cost system developed by the team that integrates air pollution, meteorological data and location tracking. This novel system facilitates the simultaneous and comprehensive assessment of multiple parameters, enhancing the efficiency of the data collection process. This is particularly significant given that Portugal's fixed air quality monitoring network is sparse, which limits the ability to conduct localised and individual-level health research. Furthermore, the project will employ CoDA to investigate 24-hour movement behaviour composition, providing a better understanding of how different movement behaviours interact and contribute to health outcomes throughout the day, which will offer information that conventional analyses might fail to capture.

Despite its strengths, the MOVE-AIR project will face several challenges. Ensuring consistent and accurate data collection across multiple settings and participants requires meticulous planning and execution. Similarly, measuring children's exposure to air pollution presents logistical challenges, especially in terms of ensuring compliance with the monitoring protocol. To ensure the continuity, integrity and feasibility of the MOVE-AIR study, a comprehensive contingency plan has been developed to anticipate and address potential challenges during the research process. In the event of difficulties in participant recruitment, such as low enrolment or parental non-consent, the research team will consider extending recruitment to additional preschools in the region. This will be accompanied by enhanced communication strategies with the Northern Regional Educational Board.

In the case of equipment malfunction or technical issues related to portable air monitors and accelerometers, a set of backup devices will be maintained and pretested to ensure readiness. Devices will be systematically checked before deployment, and data integrity will be monitored during the collection phase to allow early detection of issues.

Access restrictions to preschool environments, potentially caused by institutional closures or external disruptions (eg, health-related shutdowns or labour strikes), will be managed through flexible scheduling and continuous coordination with school leaderships. If needed, alternative data collection locations or rescheduling will be pursued. Similarly, environmental or weather-related factors, which could affect outdoor activity and air quality measurements, were considered and data collection will happen in the same seasonal period for all the children. Where necessary, adjustments to the timeline will be implemented and transparently communicated to relevant stakeholders. Additionally, research staff turnover will be addressed through cross-training and detailed documentation of protocols to facilitate smooth transitions and uphold data quality.

Furthermore, the cross-sectional study design of the MOVE-AIR project will limit our ability to establish causal relationships. Additionally, our focus on a convenience sample of schools in specific geographical locations and seasonal period of the years may affect the external validity of the study.

Author affiliations

[1]Research Centre in Physical Activity, Health and Leisure; Faculty of Sport, University of Porto, Porto, Portugal
[2]Laboratory for Integrative and Translational Research in Population Health (ITR), Porto, Portugal
[3]EPIUnit - Public Health Institute University Porto (ISPUP), Porto, Portugal
[4]Centre for Translational Health and Medical Biotechnology, Higher School of Health, IPP, Porto, Portugal
[5]University of Coimbra, Interdisciplinary Center for the Study of Human Performance, Faculty of Sport Sciences and Physical Education, Coimbra, Portugal
[6]Nucleus of Research in Human Motricity Sciences, Universidad Adventista de Chile, Chillán, Chile

[7]Laboratory of Sport Physiology, Faculty of Sports, University of Porto, Porto, Portugal
[8]Department of Public Health and Forensic Sciences and Medical Education, Faculty of Medicine, University of Porto, Porto, Portugal

X Rodrigo Zacca @rodrigozacca and Ana Isabel Ribeiro @AnaIsaRibeiro

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Contributors CM: conceptualisation, ethical approvals, project administration, methodology, writing—original draft. JCR: conceptualisation, methodology, writing—review and editing. AP, HF, LCB, MPS, MS, RZ, JPS: methodology, writing—review and editing. AIR: conceptualisation, project administration, methodology, writing—original draft. CM is the guarantor and accepts full responsibility for the integrity and accuracy of the work presented. She affirms that the data, analysis and conclusions presented in the article are accurate, reliable and contain no conflict of interests.

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ORCID iDs
Miguel Sousa http://orcid.org/0009-0009-0676-5956
Ana Isabel Ribeiro http://orcid.org/0000-0001-8880-6962

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