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Visiting natural open spaces in urban areas during pregnancy and its association with daily physical activity

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A B S T R A C T

We examined the association between visiting natural open spaces (NOS) and physical activity (PA) at different trimesters of pregnancy. We used GPS and accelerometer data from women residing in Donostia-San Sebastian and Barcelona. Daily visits to NOS were associated with an increase of circa 8 min of moderate to vigorous physical activity (MVPA) in the first and second trimesters of pregnancy. Women who visited NOS were more likely to meet the WHO daily PA guidelines during the first trimester. Visiting NOS can promote PA consistently during pregnancy, improving maternal health and well-being in urban settings.

1. Introduction

In recent years, the scientific and social interest on benefits of green and blue spaces for human health and well-being has rocketed. Natural open spaces (NOS) within or around urban areas, including green spaces such as parks or blue spaces such as waterfronts or canals, among many other settings, can promote physical activity (Benton et al., 2021; Evenson et al., 2016) and thus contribute to a better health. In fact, the promotion of physical activity (PA) is one of the main pathways linking NOS to human health and well-being according to researchers in the field (Dzhambov et al., 2020; Markevych et al., 2017; White et al., 2020). Epidemiological studies usually operationalize exposure to NOS by means of Geographic Information Systems (GIS) that allow to calculate different metrics such as the Normalized Difference Vegetation Index (NDVI) (Nordbø et al., 2018) in residential, work and/or educational settings and then compare PA levels among participants exposed to different levels of greenness.

Some studies with adult populations using said methodology have shown that residing closer to green parks (Gidlow et al., 2019; Shen et al., 2021) or blue settings (Gascon et al., 2017) or living in greener neighborhoods (García De Jalón et al., 2021; Liu et al., 2019) can promote PA, although the evidence is not always consistent. For instance, in

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[1] In loving memory of Dr. Guillem Vich (1982–2022), a valued colleague and trusted friend.

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a review of 26 studies analyzing the pathways between GIS-based green metrics and mental health and well-being, only 8 of the 16 studies including the PA pathway confirmed the expected positive connection (Zhang et al., 2021). In the review conducted by Gascon et al. (2017), only 7 out of 13 studies on exposure to blue spaces showed positive and statistically significant associations with PA. More recent research is still equivocal with works showing positive results but only for some metrics. Juul and Nordbø (2023) examined whether NDVI and the proportion of green space in the residential area were associated with PA in a sample of 5670 Norwegian adults and found that only the former reached statistical significance. In another study with more than 4000 Chinese senior adults, the authors found that green view at the street level in the residential area positively predicted PA but NDVI, and proximity to parks did not (Xiao et al., 2022). In the same vein, a recent work conducted in Australia with a sample of 350 adults showed a negative link between distance to the coast, measured as Euclidean distance from the participants' address to the coast, and PA (Murrin et al., 2023). The authors also examined the effects of distance to inland water bodies (e.g., lakes or rivers) and found a negative association with PA levels, although it was smaller in size.

The use of GIS-based green and blue exposure metrics comes with several limitations that have been clearly acknowledged elsewhere (Kwan, 2012, 2018; Labib et al., 2020) and might be behind those inconsistencies. For example, standard approaches in environmental epidemiology and related disciplines (i.e. geography, urban planning) assume arbitrary boundaries to define exposure environments such as residential or work settings which may or may not correspond to participants' mental representations of said environments and their actual patterns of use (Vallée et al., 2015). This relates to the issue of the Uncertain Geographic Context Problem (UGCoP), which refers to the difficulty in eliciting the correct scale and spatial unit to assess the influence of environmental factors on individual behavior or a given outcome such as PA (Kwan, 2018). On the other hand, most studies assume that NOS such as green spaces are generally accessible, or that people living or working close to a NOS actually use it (Dadvand et al., 2019), or use Euclidian distances in assessing access (Zhou and Xu, 2020). In response to these limitations, data on frequency and length of use has been gathered via questionnaire in a selected group of studies (Gomm and Bernauer, 2023; McEachan et al., 2018; Zhang et al., 2022). However, this procedure comes with the additional assumption that the visits to NOS that participants report do refer to the NOS assigned to them (e.g., this/those being closer to their house or workplace). In this context, available location-aware technologies such as location-based service data, mobile service data or GPS-based devices, among others, can aid in moving from the static exposure metrics described above towards dynamic and more precise accounts of individual movement in general, and of exposure to NOS in particular (Chen et al., 2022; Marquet et al., 2022; Song et al., 2021). More specifically, the use of such technologies allows, first, to provide a more precise account of participants' interaction with areas of interest (i.e., green spaces); second, it can more easily capture temporal variability when data is gathered in the span of several hours or days, compared to having one single measure of exposure (e.g., residential environment); lastly, it also allows to mitigate recall biases inherent to self-reported data collected by diaries or questionnaires, while reducing participation burdens. Moreover, when combining precise location-based technologies such as GPS devices with accelerometry devices, it permits the detection of place/s where participants perform PA while providing with detailed information to understand the specific contribution of NOS to PA time (Jankowska et al., 2015).

In terms of the relationship between NOS and PA, there is a growing number of studies that have utilized precise location-aware devices such as those based on GPS to assess the exposure to such spaces beyond the residential environment. Recently, for example, Roberts and Helbich (2021) used GPS-enabled smartphones to identify associations between exposure to green spaces (both static and dynamic) and depressive symptoms in the Netherlands. Similarly, Kan et al. (2023) used GPS devices and mobile sensing to examine associations between dynamic exposure to greenspace, air pollution and noise. More specifically, there are also some studies that have focused precisely on identifying visits to parks or other forms of green spaces (Evenson et al., 2013; Stewart et al., 2016; Vich et al., 2021). Lastly, and what is of particular interest to our study, only very recently some studies have relied on GPS-based measures of mobility patterns as well as exposure to everyday locations among pregnant women. Yi et al. (2022) analyzed GPS daily mobility patterns among 62 pregnant women from the MADRES cohort living in Los Angeles, and found that commercial and service locations were the most frequently visited, while parks and open spaces were seldom visited, and decreased as pregnancy was more advanced. In a more recent study, Yi et al. (2024) analyzed the same group of women to assess the potential for measurement error in residential vs GPS-based estimates in terms of access to transit, parks and walkability, and found that GPS-based measures were more representative of participants real exposure compared to residential measures.

1.1. PA during pregnancy and NOS

PA is strongly recommended during pregnancy (Bull et al., 2020; WHO, 2020). It has been shown that it reduces the risk of gestational diabetes (Artal, 2015; Dipietro et al., 2019), macrosomia (Davenport et al., 2018), preeclampsia (da Silva et al., 2017), and assisted or caesarean delivery (Davenport et al., 2019). It also helps to maintain muscle strength, agility, coordination and cardiovascular endurance (Artal, 2015; De Oliveria Melo et al., 2012; Price et al., 2012), increases sleep quality (US Department of Health and Human Services, 2018) and decreases stress (Sinclair et al., 2019) and blood pressure levels (Sobierajski et al., 2018). Given that women tend to reduce their levels of PA during pregnancy (Borodulin et al., 2008; Downs et al., 2015; Evenson et al., 2004; Pereira et al., 2007), it is key to analyze the environmental factors that might be supportive of PA during said specific period.

There have been some attempts to disentangle the effects of NOS on PA during pregnancy, although most studies have focused on green spaces specifically. Nichani et al. (2016) found that New Zealander pregnant women residing in areas with greater proportion of green spaces were more likely to meet pregnancy PA recommendations and López-Gil et al. (2022) reported that living near to a safe green space increased the odds of meeting said recommendations in a sample of Colombian women. However, another study conducted in the US with 2,006 pregnant women showed that distance to the nearest park was not associated to PA (Porter et al., 2019). All these studies used self-reported measures of PA, which have shown low to moderate levels of agreement with objective-based measures in previous studies (Mendinueta et al., 2020; Skender et al., 2016). In a previous study with samples of pregnant women in Donostia-San Sebastian and Barcelona who used accelerometry devices, the authors found that perceived greenness was positively associated to light PA in Donostia-San Sebastian but negatively associated to moderate to vigorous PA in Barcelona (Subiza-Pérez et al., 2021). In conclusion, studies on the role that NOS play in PA during pregnancy are scarce and their results are inconsistent, which warrants further investigation. Also, and as mentioned above, the consideration of NOS other than green spaces, such as blue spaces, has also been limited, as pointed out by Akaraci et al. (2020).

1.2. Study objective

In this paper, we used data collected for the Urban Green Activity and Reproductive Effects Study (UGARE) in two Spanish cities, namely Donostia-San Sebastian and Barcelona. The analyses presented here were conducted with a twofold objective. We aimed at testing the association between visiting NOS within cities and daily PA levels among pregnant women, and examine said association at two points in time during pregnancy. The fact that GPS and accelerometry data were available for UGARE participants in the first and second trimesters of pregnancy allowed us to address these objectives.

2. Methods

2.1. Study setting

This study is set in Donostia-San Sebastian and Barcelona (Spain) (Fig. 1). These two cities are considerably different, both in terms of climate and urban configuration. Donostia-San Sebastian is in the Basque Country, on the northern side of the Iberian Peninsula, along the coast of the Bay of Biscay. Donostia-San Sebastian has a population of 187,849 (INE, 2022) inhabitants in its main municipality, and over 318, 000 when its surrounding metropolitan area, mostly corresponding to the county of Donostialdea, is considered. This region features a humid subtropical climate according to the Köppen classification, characterized by warm summers and cool winters, with approximately 1500 mm of precipitation spread throughout the year (AEMET, 2023).

Barcelona, on the other hand, is situated on the northernmost part of the Mediterranean coast of the Iberian Peninsula and serves as the capital of Catalonia. The municipality of Barcelona is home to 1,636,193 inhabitants (INE, 2022), with a metropolitan area exceeding 3.3 million. Climatically, this region presents a hot-summer Mediterranean climate, characterized by dry and hot summers, as well as mild winters, with an annual rainfall of approximately 600 mm that primarily occurs in the fall and spring (AEMET, 2023).

Corresponding to both their climatic conditions and demographic size, the cities of Donostia-San Sebastian and Barcelona also exhibit significantly different urban configurations. On one hand, Donostia-San Sebastian is characterized by lower population density levels, an urban form that is more compact at its center but more scattered in its peri-urban area, and consequently, a higher prevalence of NOS within and around the city. On the other hand, Barcelona is one of the densest urban areas in Europe and is characterized by a very compact urban form, with little room for NOS within the city, but with access to blue spaces and large green spaces in the outskirts (Fig. 1).

2.2. Participants

Participants were recruited during their first-trimester ultrasound appointments at the gynecology services of the public health service in Donostia-San Sebastian and Barcelona, throughout 2018. Women were approached after their appointment, and willing participants were requested to provide informed consent for the study and were administered a questionnaire pertaining to their sociodemographic characteristics and daily habits. We excluded participants based on the following criteria: having a multiple pregnancy[b], lacking sufficient communication abilities in Basque, Catalan, Spanish, or English, and not being a resident within the study area throughout the entire research duration. Additionally, women at high risk of fetal chromosomopathy (>1/270; Álvarez-Nava et al., 2003) or those with an escalated risk of fetal cardiopathy stemming from an increased nuchal fold measurement in the first trimester (>p 95; Sharifzadeh et al., 2015) were not included in the study. Participants were required to carry two devices for 7 days: a waist-worn accelerometer (ActiGraph © GT3X+) to measure their physical activity levels and a GPS logger (QStarz © BT-Q1000XT GPS) to record their location every 15 s. Participants who had taken part in the first round of the study were later recontacted at their second-trimester ultrasound appointments. Those willing to take part in the second study period were required to wear the devices again for 7 additional days. The study was approved by the Research Ethics Committee of the Health Department of the Basque Government (Ref. no PI2018108) and the Ethics Committee of the Hospital del Mar (reference number: 2018/8373/I). Data collection took place between October 2018 and December 2019 in Donostia-San Sebastian and between April 2019 and February 2020 in Barcelona.

2.3. Outcomes

Several PA indicators were used as outcome variables in our study. Raw data was processed using the HABITUS software as in previous studies (Campos-Garzón et al., 2023). HABITUS stands for Human Activity Behavior Identification Tool and Data Unification System, and consists of a web-based platform (https://www.habitus.eu) that not only allows processing accelerometer and GPS data, but also to merge them based on their common timestamps in a user-friendly interface. HABITUS is based on the earlier PALMS system (Personal Activity Location Measurement System) (Carlson et al., 2015), also widely used in similar studies. Additionally, this tool allows to classify levels of physical activity according to cut points specified by the user, which in our case were those defined by Freedson et al. (1998). Specifically, we assessed the following outcomes: (1) daily duration (in minutes) of light physical activity (LPA), (2) daily duration of moderate to vigorous physical activity (MVPA), and (3) daily adherence to the WHO's specific guidelines for physical activity for pregnant and postpartum women (WHO, 2020). Subsequently, measures of LPA and MVPA have been commonly used in studies with pregnant women (López-Gil et al., 2022; Mendinueta et al., 2020; Nichani et al., 2016). We defined adherence as having achieved 21.42 min of MVPA on a given day, which corresponds to dividing the weekly recommendation of 150 min of MVPA by seven days. Moreover, this value approximately corresponds to the MVPA min/day associated with the highest risk reduction in all-cause mortality, of around 23 min (Ekelund et al., 2019). For days of participation to be considered as valid in the analysis, we applied a threshold of minimum device daily wear time of 10h, as suggested when pairing GPS and accelerometer data for physical activity analyses (Jankowska et al., 2015).

2.4. Key exposure

The key exposure variable was defined as a binary variable (No/Yes), indicating whether participants had visited at least one NOS on a given day. NOS include any type of natural open space in Donostia-San Sebastian and Barcelona, considering both green and blue spaces. For this purpose, we used data from European Urban Atlas (2018) land cover dataset, from the European Environment Agency (EEA, http://www.eea.europa.eu/dataand-maps/data/urban-atlas), which provides land uses and land covers for urban zones with over 100,000 inhabitants and which has been used in similar studies (Kabisch et al., 2016; O'Callaghan-Gordo et al., 2018). In terms of green spaces, we considered urban parks but also forests, wetlands, and other vegetated areas such as herbaceous vegetation or crops. In terms of blue spaces, we considered both beaches and riverside areas.

We defined visits to NOS based on GPS activity, based on definitions in previous studies (Evenson et al., 2013; Stewart et al., 2016; Thierry et al., 2013; Vich et al., 2021; Yi et al., 2022). However, while some previous studies had generally defined visits as spending at least 3 consecutive minutes in or near a NOS (Evenson et al., 2013; Stewart et al., 2016; Vich et al., 2021), we opted for a more restrictive threshold and thus we considered 'visit' a sequence of at least 5 consecutive minutes within 10 m from a NOS. We used a 5 min threshold based on the work by Thierry et al. (2013), which has also been recently used in a study that also examines visits to natural spaces among pregnant women (Yi et al., 2022). We applied the 10 m tolerance radius considering that while the GPS device manufacturer specifies an overall accuracy of <3 m, our study focuses on dense urban environments, where GPS accuracy

[b] Given the potential impact of multiple pregnancies on physical activity and pregnancy outcomes, the main outcomes in the UGARE project, we decided to exclude women with those.

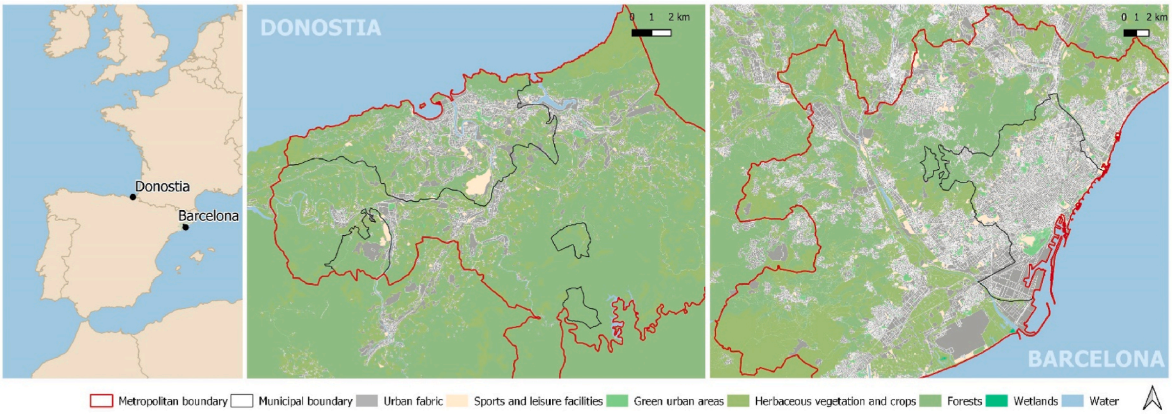

Fig. 1. Maps of Donostia-San Sebastian and Barcelona (Spain).

can be significantly lower, and thus aiming to avoid location errors of GPS devices that could imply incorrectly labeling visits to NOS, as suggested in a recent paper (Vich et al., 2021). We also excluded behavior within a 100 m buffer from participants' own residences (see Fig. 2for an illustration) to avoid noise derived from the GPS signal when stationary indoors.

Previous studies examining the relationship between the built environment and physical activity have used a myriad of measurements of contextual exposure (i.e., domain-based, buffer-based, activity space-based), and have focused on very different aspects related to the interaction with certain spaces such as parks or open spaces, including not only visits to these spaces, but also time spent in them or their characteristics (e.g. size) (refer to Smith et al., 2019; Yi et al., 2019 for detailed reviews on such measures of exposure). However, in this case we decided to operationalize our key exposure to NOS using a "No/Yes" format at the daily level (i.e. not having or having visited at least one NOS daily), considering that daily visits to NOS among our sample showed a skewed distribution with a median number of daily visits of 0 (p25 = 0, p75 = 1) in Barcelona in both trimesters, and 1 (p25 = 0, p75 = 3) in Donostia-San Sebastian in both trimesters (see Table 1). A similar approach was applied in a previous study also set in Barcelona (Vich et al., 2021). Having a low frequency of visits to NOS on a daily basis is understandable, as these are not necessarily everyday locations, as found also in a similar study examining visits to parks and other open spaces among pregnant women (Yi et al., 2022).

Table 1
Description of physical activity levels and visits to NOS per participant-day, per trimester and city.

	1st Trimester		2nd Trimester	
	BCN, N = 467	**DON**, N = 921	**BCN**, N = 176	**DON**, N = 399
Daily LPA time (min)	178.0 (131.2, 230.0)	186.2 (143.8, 234.5)	173.5 (138.1, 222.5)	190.8 (151.0, 234.6)
Daily MVPA time (min)	45.8 (27.8, 64.2)	44.0 (26.2, 68.5)	41.1 (22.8, 63.3)	44.5 (26.0, 68.5)
Daily NOS visits	0.0 (0.0, 1.0)	1.0 (0.0, 3.0)	0.0 (0.0, 1.0)	1.0 (0.0, 3.0)

Values correspond to median (quartile 1, quartile 3). BCN = Barcelona, DON = Donostia-San Sebastian, LPA = Light physical activity, MVPA = Moderate to vigorous physical activity, NOS = Natural open spaces.

2.5. Covariates

Based on the available literature and the data gathered for the study, a set of variables was selected as potential covariates for this study (see Supplementary Table 1 for a description of the sample). This set comprised individual variables such as age, educational attainment, body mass index (BMI), the number of children previous to the ongoing pregnancy, employment status, physical demands of the main activity, whether the participant was in work leave, if she was recommended to rest during pregnancy, residential preferences, main daily mode of transport and PA level of enjoyment. All these variables were measured via questionnaire. Using GIS software and census data we also calculated

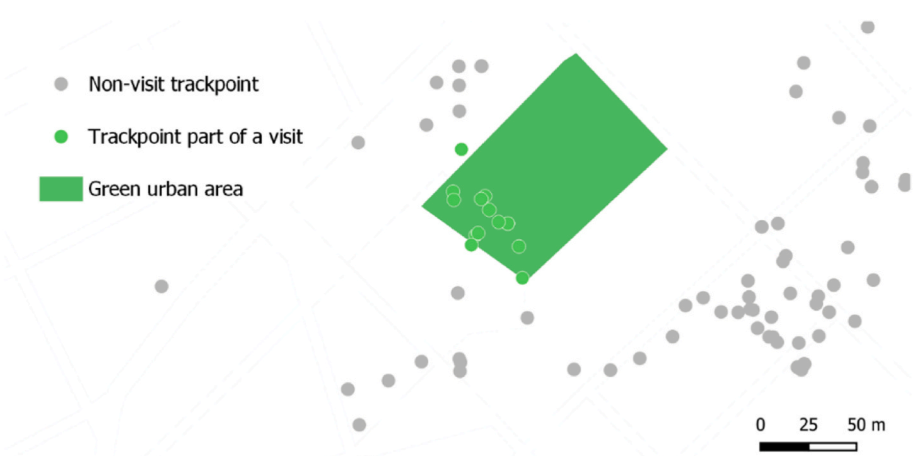

Fig. 2. Abstract example of visit to a Natural Open Space (NOS).

for each participant the population density of their residential area, average household income per census district in 2017, and availability of major NOS (>5000 m^2) in a 300m radius from the household (based on WHO recommendations, WHO Regional Office for Europe, 2016).

2.6. Analysis

As in similar studies, our data is structured in two levels. At one level, we registered the participants' sociodemographic characteristics and day-to-day habits and routines. At a second nested level, we registered the participants' activity during different days, as well as data regarding their visits to NOS. Considering that our aim was to assess the association between visits to NOS and daily physical activity levels, we used R software to fit a set of mixed-effects regression models, as outlined by Dean and Nielsen (2007) and Faraway (2016). Thus, to model outcomes, the fixed-effects part of the models included both the key exposure and the appropriate covariates (see the paragraph below). The random-effects part of the said models included the specification of a random factor to indicate that observations were nested (grouped) within participants. Likewise, we attempted to introduce an additional factor, as a further random effect, but, as indicated by the comparison of AIC values (Faraway, 2016), this did not yield a significant improvement in the models' fit (see Supplementary Tables 1 and 2). In all cases, we used the canonical link functions and only cases with complete observations for all the relevant outcome, key exposure, and selected covariates. For the models in which the outcome was either LPA or MVPA daily times, we resorted to Gaussian regression via the R package nlme (Pinheiro et al., 2022; Pinheiro and Bates, 2000); in these cases, with the goal to further control for temporal autocorrelation in within-individual measurements, we used the argument < correlation> of the function lme () to introduce a correlation structure term (an autoregressive process of order 1). For the cases in which the outcome was relative to the achievement of WHO PA guidelines, we fitted binary (logistic) regression models via the R package lme4 (Bates et al., 2015). In reporting our results, we took care to follow relevant guidelines (Bono et al., 2021).

We selected the sets of covariates to be used in the models by designing a Direct Acyclic Graph (DAG; available in Fig. 3). A DAG needs to be constructed after careful review of the relevant literature and then discussed with co-authors and colleagues, as it must display the expected relationships between variables involved in the phenomenon of interest. In this case, the phenomenon of interest is the contribution of NOS to PA during pregnancy. The DAG is then a complex working hypothesis that reflects current scientific evidence and the theoretical assumptions held by the researchers. In other words, a DAG is a relatively simple representation of how the researchers think the world works. Once we fully agreed on the DAG to be used in the study, we followed the procedure described in in Ankan et al. (2021) to check testable implications. Checking those assumptions required the use of functions included in the R packages dagitty (Textor, 2020) and lavaan (Rosseel, 2012). In line with previous research (Subiza-Pérez et al., 2023a; 2023b), we considered that a testable implication was unmet when its associated r coefficient was larger than 0.20 and had a p-value below the 0.05 threshold. This DAG validation process was conducted independently for each combination of trimester-outcome and its results are shown in Appendix I. After detecting previously unspecified relationships between variables by means of the said testable implications, we amended our initial DAG (see Supplementary Figs. S1 and S2). Then, we determined the sufficient adjustment sets for the models. This way, first trimester models included age, active transport use, education level, number of previous children and PA enjoyment level as covariates. For models using second trimester data, we used area socio-economic status (SES), population density,

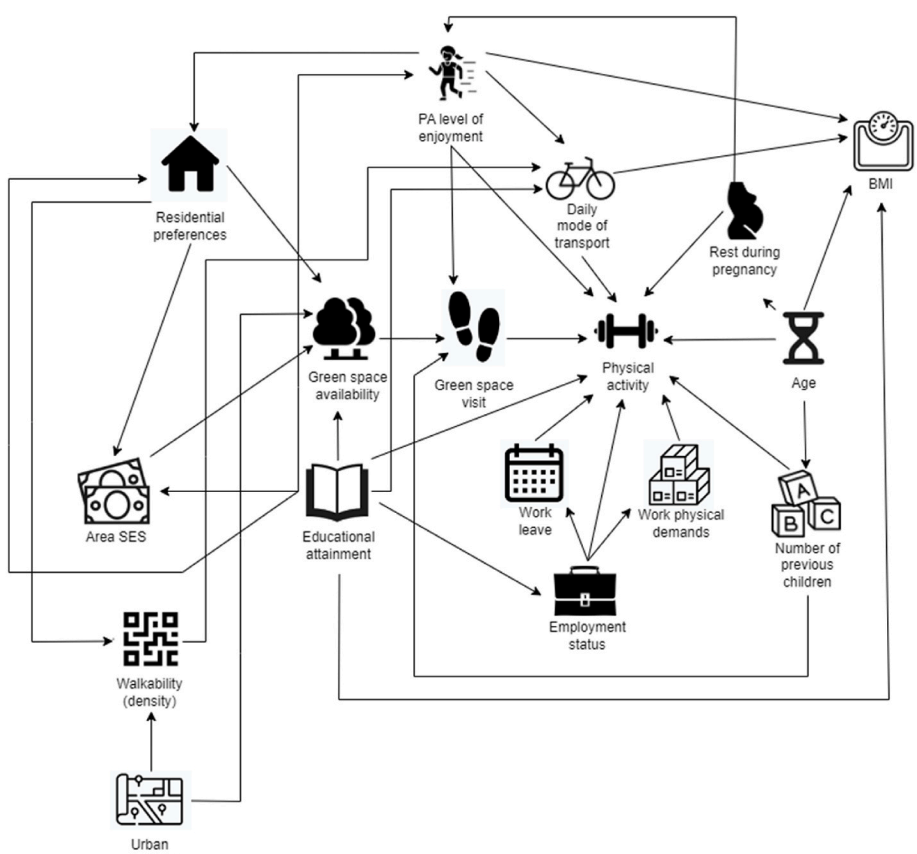

Fig. 3. Directed Acyclic Graph regarding the expected associations between green space visit (as an example of NOS) and physical activity engagement. Urban planning is an unobserved variable.

education level, number of previous children, PA level enjoyment and PA related to main activity.

3. Results

3.1. Sample description

A total of 805 women (441 from Donostia-San Sebastian, 364 from Barcelona) were initially enlisted for the study. Ultimately, 426 women recorded at least one day of valid data (with over 10 h of data) from both devices during the first trimester or 1T (280 from Donostia-San Sebastian, 146 from Barcelona), while 177 women recorded valid data during the second trimester or 2T (125 from Donostia-San Sebastian, 52 from Barcelona).

A detailed overview of the characteristics of women from the first trimester questionnaire is presented in Supplementary Table 1. Most participants were between 30 and 39 years old, had normal weight, had university education and were working at the time of the study, and less than 10% of the sample had been recommended resting during pregnancy. Approximately half of the participants in the study had a previous child, and most participants enjoyed PA a little bit or moderately and had slightly or moderately active main activities (e.g., work). In terms of differences between cities, participants in Barcelona more frequently resided in denser and low-income areas and, in line with the previous description of the cities, residents in Donostia-San Sebastian had more access to NOS from their home addresses. Lastly, we observed only a small proportion (14%) of participants that could present a residential bias when interpreting their association between NOS visits and PA (i.e., participants who chose their home location based on the environmental aspects of the neighborhood such as the provision of NOS).

3.2. Daily physical activity levels and visits to natural open spaces

Data presented here correspond to the 1388 and 575 person-day GPS and accelerometry valid pairings we obtained for the first (426 women) and second (177 women) trimesters respectively. Participants analyzed in the first trimester appear to have engaged in some kind of physical activity for approximately 3h and 45 min daily in both cities, consisting of 178 and 186.2 min of light physical activity or LPA, and 45.8 and 44 min of moderate to vigorous physical activity (MVPA), in Barcelona and Donostia-San Sebastian, respectively (Table 1).

Physical activity levels were slightly different among the analyzed participants in the second trimester. In Barcelona, participants showed slightly lower levels of both LPA (173.5 min) and MVPA (41.1 min), while in Donostia-San Sebastian we found the opposite case, where participants showed slightly higher levels of physical activity, especially in terms of LPA (190.8 min).

In terms of visits to natural open spaces (NOS), in both trimesters participants in Barcelona had a median value of 0 visits to NOS, in line with a lower provision of such spaces in the city. On the other hand, participants in Donostia-San Sebastian showed a median of 1 visit per day in both trimesters. A basic description of visit characteristics is provided in Supplementary Table 4.

3.3. Association between NOS visits and daily PA time

Results of the mixed-effects models of the associations between visits to NOS and the different PA levels with data from the first trimester are presented in Table 2. We found no significant association between visiting NOS and daily LPA time when adjusting by potential confounders. Conversely, we found a strong and positive association between having visited at least one NOS and daily MVPA time (B = 7.9, p = 0.001). This association suggests that in the first trimester, having visited at least one NOS was associated with an increase of 7.9 min in daily MVPA time.

When we analyzed data from the second trimester the results are consistent (Table 3). Again, we observed no significant association between having visited at least one NOS daily and LPA levels. The association between NOS visit and MVPA time seems consistent with that observed with data from the first trimester, showing a positive yet weaker (in terms of the p-value) association (B = 8.22, $p = 0.048$). In this case, our results suggest that in the second trimester having visited at least one NOS was associated with an increase in 8.2 min of MVPA time daily.

The results from the models using the daily MVPA WHO recommendations indicate that NOS visits increased the odds of meeting the recommended PA time in the first trimester (OR = 2.04, $p = 0.004$) but not in the second one.

4. Discussion

Greenness and green spaces might contribute to increased PA during pregnancy. A reduced number of previous studies analyzed whether static greenness metrics predicted PA levels in samples of pregnant women and results were mixed. Nichani et al. (2016) found that those living in greener areas were more likely to show increased PA levels during the first trimester of pregnancy, although the effect disappeared in fully adjusted models. The study by Porter et al. (2019) did not find any association between distance to parks and PA whereas a Colombian study found reported that living closer to green spaces increased the odds of meeting MVPA guidelines. In this study, we wanted to contribute to this body of evidence by using dynamic accounts of NOS use. More specifically, we aimed to examine the relationship between visiting NOS and daily PA levels during the first and second trimesters of pregnancy, which were measured with GPS and accelerometer devices. While we did not observe a significant association between visiting NOS and LPA in either trimester, we found a noteworthy and consistent positive association with MVPA in both trimesters (1T and 2T). Pregnant women who visited NOS at least once on a given day engaged in approximately 7.9 min more MVPA in 1T and 8.3 min more in 2T, compared to those who did not visit. While relevant, the approximate 8-min gain in daily MVPA associated with visiting NOS observed in our study is smaller than the gain reported in previous studies focusing on other demographic groups (i.e., older adults; Vich et al., 2021).

The observed increments in PA imply that, at least in 1T, pregnant women visiting NOS were twice as likely to achieve the WHO's daily MVPA recommendations. This is of particular interest, since a recent study has evidenced that PA should be promoted above WHO guidelines

Table 2
Adjusted association between having visited at least one NOS and LPA and MVPA time (minutes), and the likelihood of meeting WHO PA guidelines, in the first trimester (n = 906).

	Coefficient (B/OR)	Std. error	df	t-value	p	95% CI
LPA time (min)	−1.30	4.23	615	−0.31	0.759	(-1.30, 7)
MVPA time (min)	7.87	2.15	642	3.66	<0.001	(3.64, 12.09)
Meeting WHO daily recommendation	2.04	0.25	860	2.87	0.004	(1.25, 3.32)

Models adjusted by age, active transport use, education level, number of previous offspring and PA enjoyment level. LPA model performance indicators: AIC=16606.31, BIC=16663.41, logLik=-8291.157. MVPA model performance indicators: AIC=16119.64, BIC=16177.23, logLik=-8047.82. WHO daily recommendations model performance: AIC=757.54, BIC=805.22, logLik=-368.77. LPA = Light physical activity, MVPA = Moderate to vigorous physical activity.

Table 3
Adjusted association between having visited at least one NOS and LPA and MVPA time (minutes), and the likelihood of meeting WHO PA guidelines, in the second trimester (n = 370).

	Coefficient (B/OR)	Std. error	df	t-value	p	95% CI
LPA time (min)	−3.46	6.38	255	−0.54	0.588	(-16.03, 9.11)
MVPA time (min)	8.22	4.14	255	1.99	0.048	(0.08, 16.37)
Meeting WHO daily recommendation	1.27	0.35	359	0.67	0.497	(0.63, 2.55)

Models adjusted by census tract income, population density, education level, number of previous children, PA level enjoyment and PA related to main activity. LPA model performance indicators: AIC=6967.68, BIC=7025.89, logLik=-3468.84. MVPA model performance indicators: AIC=6736.37, BIC=6794.58, logLik=-3353.19. WHO daily recommendations model performance: AIC=359.60, BIC=410.50, logLik=-166.80. LPA = Light physical activity, MVPA = Moderate to vigorous physical activity.

during the first trimester in order to help reducing high glucose levels and the risk to develop gestational diabetes (Ehrlich et al., 2021). Moreover, we also observed that the association between NOS visits and PA gain remained consistent, and even showed a slightly stronger association (in terms of increased MVPA time), in the second trimester.

Adding to the temporal consistency of the observed association between NOS visits and PA, we also found no differences in two cities that significantly differ in terms of availability of NOS. This would imply that a higher availability in NOS (in Donostia-San Sebastian) triggers greater use of NOS but does not modify the size and nature of the association between NOS and PA during pregnancy. In turn, this might suggest that the positive impact of NOS on PA during pregnancy transcends urban settings and could point at the potential universality of this relationship. However, further studies using similar methodologies in other locations are warranted to support this claim. For instance, our results are different from previous studies in terms of visits to NOS, as derived from a higher visitation rate compared to what was found in a recent study focusing on pregnant women in Los Angeles, who seldom visited parks and open spaces during pregnancy (Yi et al., 2022).

From a policy perspective, we see that our work has several practical implications. First, once we have demonstrated the contribution of NOS to PA during pregnancy, interventions to increase access to NOS are crucial. One clear area of improvement would be the strengthening of public transport networks and services, given the fact that women tend to resort to public transport more often than other populations (Cresswell and Uteng, 2008; Hanson and Pratt, 1995). Second, we have seen that the increase in PA associated with the use of NOS is evident even in a city with low provision of NOS (i.e., Barcelona), which informs about the value of any intervention aiming at increasing the provision or usability of any number of NOS. Given the spatial constraints of large, and especially high-density cities, such as Barcelona, we consider that the implementation of green corridors might be a valid intervention to promote the use of already existing NOS and PA (Aman et al., 2022; Zhang et al., 2019). In turn, if such spaces are indeed attractors of PA, they need to be adequately designed to meet the needs from a diverse spectrum of users, which in the case of pregnant women could imply, for example, the provision of enough shaded areas, public fountains, or public toilettes. Finally, and from a medical perspective, general practitioners and other health professionals working with pregnant women could include NOS prescriptions into their usual health recommendations in order to improve their health and well-being (Korpela and Ylén, 2009; Twombly, 2010).

One of the main strengths of our work is the combination of GPS and accelerometry to account for visits to NOS and measured PA levels. This approach has allowed us to focus on use of NOS rather than access or availability (either objective or perceived), while, at the same time, employing objective accounts of both NOS visits as well as PA engagement levels. In a previous study within this research project, the authors found that perceived greenness negatively predicted MVPA in Barcelona, a finding that was somewhat difficult to explain (Subiza-Pérez et al., 2021). However, in this study we observed a positive association between objectively and dynamically-measured NOS visits and MVPA, which underscores the relevance of dynamic accounts of the exposure to the built environment in general, and to NOS in particular, compared to focusing on daily spatial anchors such as residences or workplaces (Chaix et al., 2013; Holliday et al., 2017). Secondly, we used DAGs and the principles of robust causal inference to select confounders and obtain reliable estimates of the effects we were interested in. Finally, we conducted our study with a relevant population due to the impact of well-being and mental health status during pregnancy not only on women's health but also on that of the offspring.

However, our study is affected by limitations that need to be acknowledged, and which could inform future studies. While we observed a strong and positive association between visiting at least one NOS and daily PA engagement, in our study we did not examine whether the observed MVPA gain is related to activities conducted within NOS (e.g., brisk walking, running), or the physical activity associated with accessing these spaces (e.g., walking or cycling there). Future studies could aim at segmenting visits to NOS and specifically analyzing PA contributions of each segment (i.e., trip to access NOS, time spent within NOS, trip to egress from NOS). This distinction would provide a more nuanced understanding of the relationship between NOS visits and PA, especially considering that the association was observed in relation to MVPA and not to LPA. Similarly, in our study we focused on a simple and clear measure of exposure, by categorizing days as visit or non-visit days, derived from the low number of visits per day. In this sense, an interesting avenue for future research focusing on pregnant women would be to conduct a specific exploration of visit characteristics (e.g. type of activities, intensities, type of places visited within NOS) to examine how these are associated with PA engagement (Miralles Guasch et al., 2019). Also, samples were not representative and therefore our ability to generalize our results to the whole population of pregnant women in Donostia-San Sebastian and Barcelona is compromised. The recruitment of representative samples of the population would help to overcome this limitation and would allow to investigate whether factors such as age, SES, or previous PA habits modify the association between NOS visits and PA levels. Another point that deserves mention here is that we did not take into account visit to NOS outsides the metropolitan areas where participants resided, which is a clear avenue for future research. Besides, despite our study is to our knowledge the first to examine the association between NOS and PA at two points in time during pregnancy, our data is affected by two factors that should be considered in future studies. On the one hand, we believe that the burden that the use of wearable devices can put to pregnant women (Runkle et al., 2019), resulted in, first, a lower initial recruitment success rate, second, a lower number of correct days of valid participation and, finally, a lower participation rate and a resulting reduced sample size in the second trimester. Consequently, it would be of particular interest to improve participation rates, especially in the second trimester, in order to conduct longitudinal studies. Location-based service data (e.g., Song et al., 2021 etc.) or mobile signal data (e.g., Chen et al., 2022 etc.) might alleviate such a burden. However, these types of data might not allow for the same level of spatiotemporal accuracy as GPS-based analyses. These limitations come on the top of a potential self-selection bias in recruitment as participants took part in the study voluntarily. Still in terms of biases, dynamic exposure analysis such as the one presented in our study could be affected by the selective daily mobility bias (i.e., people interested in engaging in physical activities could also willingly choose to visit spaces such as NOS). However, we aimed to correct this in our study by means of including an indicator for PA levels of enjoyment. Finally, the 7-day periods in which the participants wore the devices might not necessarily reflect their usual park behavior as they might be insufficiently long to give a representative picture. In addition, participation in the study could have altered daily routines (e.g., invited them to visit green spaces more often than usual). Longer study participation periods could also help to reduce the potential impact of these two latter limitations.

5. Conclusion

We analyzed GPS and accelerometer data from pregnant women in Donostia-San Sebastian and Barcelona to assess the relationship between NOS visitation and daily PA engagement in the first and second trimesters of pregnancy. While we did not observe any relationship between NOS visitation and LPA, the main contribution of our study is the demonstration of a positive association between visiting NOS and daily MVPA levels among pregnant women, highlighting the potential of NOS to promote PA during pregnancy. More specifically, women who at least visited one NOS on a given day showed approximately an 8-min gain in MVPA in both the first and the second trimester of pregnancy, which at least in the first trimester was a significant contribution to achieving the WHO guidelines on PA for adults, set approximately at 21 min per day (150 min per week). This relationship was not only consistent across trimesters, but also was not significantly influenced by NOS availability of rather different urban settings. Our study has also outlined new avenues for future research that could aim to overcome the limitations presented in this manuscript and consolidate knowledge.

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CRediT authorship contribution statement

Guillem Vich: Software, Data curation, Conceptualization. **Mikel Subiza-Pérez:** Writing – original draft, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Asier Anabitarte:** Writing – review & editing, Software, Conceptualization. **Gonzalo García-Baquero:** Writing – review & editing, Supervision, Methodology. **Carolina Rueda:** Writing – review & editing, Investigation, Conceptualization. **Antoni Colom:** Writing – review & editing. **Carme Miralles-Guasch:** Writing – review & editing. **Aitana Lertxundi:** Writing – review & editing. **Jesús Ibarluzea:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Xavier Delclòs-Alió:** Writing – original draft, Software, Resources, Formal analysis, Conceptualization.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2024.103297.

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