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Interactions between dog ownership, the natural outdoor environment and health: a cross-sectional study

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Abstract

Objectives

Dog owners may receive additional health benefits as a result of walking in natural outdoor environments (NOE), but this is unknown. We investigated associations between dog ownership, walking, time spent in NOE, and health and whether these associations differed among those with better access to NOE.

Design

Cross-sectional study

Setting

The Positive Health Effects of the Natural Outdoor Environment in Typical Populations in Different Regions in Europe (PHENOTYPE) project.

Participants

3586 included adults from Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania), and Stoke-on-Trent (United Kingdom).

Data collection and analysis

We calculated access (distance, amount, and size) to NOE with land maps and surrounding greenness with satellite data. Leisure time walking, time spent in NOE, and general and mental health status were measured using validated questionnaires. Associations were estimated using multilevel analysis with a random intercept defined at the city and neighborhood level.

Results

Dog ownership was associated with higher odds of above median leisure time walking (odds ratio (OR) = 2.13, 95% confidence interval (CI) 1.82, 2.50) and above median time spent in NOE (OR= 2.42, 95% CI 2.05, 2.86). In general, better access to NOE was associated with more walking and time spent in NOE in dog owners compared with non-dog owners. No consistent associations were found between dog ownership and general or mental health status.

Conclusions

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3 Compared with non-dog owners, dog owners walked more and spent more time in NOE, especially when
4 the number of NOE around the residence was greater. The general and mental health implications of these
5 relationships should be further investigated. In a largely physically inactive society where many people
6 remain indoors, dog walking in NOE may be a simple way of promoting physical activity and health.
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10 11 12 13 14 Strengths and limitations

- 15
16 • We cannot establish the direction of the observed relationships because of the cross-sectional
17 study design.
- 18
19 • We had no detailed information about dog ownership (e.g. level of attachment, duration of dog
20 ownership, primary caretaker) and we did not know if the time spent in natural outdoor
21 environments and leisure time walking was undertaken together with the dog.
- 22
23 • This is one of the first studies from mainland Europe, and the multi-city approach revealed
24 differences between cities concerning dog ownership and health.
- 25
26 • The assessment of access to natural outdoor environments suitable for physical activity using
27 road network buffers was chosen to optimally capture the relation with people's walking
28 behavior.
- 29
30 • The use of multiple exposure indicators of natural outdoor environments enabled studying these
31 exposure indicators simultaneously, and could help understand what metric best predicts the
32 health benefits associated with natural outdoor environments.
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44 Competing interests

45
46 None declared

47 48 Funding

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8 Author's Contributions

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10
11 WLZ conducted the analyses. WLZ, HC and JL drafted the manuscript. MTM, MC, MB, JM, CG, HK,
12 WWV, SA, RG, MJN were involved in the design of and data acquisition in the PHENOTYPE study. All
13 authors provided input on the manuscript and agreed with the final version. The authors thank the
14
15 PHENOTYPE respondents for their contribution.
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18 Data sharing statement

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22 Additional data are available upon request from the corresponding author (WLZ:

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INTRODUCTION

In an urbanized world, where people spend the majority of their time indoors [1], physical inactivity is a major public health problem [2]. It not only leads to adverse health effects but it is also a large economic burden for society [3]. Physical activity behavior is influenced by the built environment [4]. Aspects of the built environment such as the availability of parks are associated with increased physical activity, especially walking [5,6]. It is important to identify sustainable built environment interventions for increasing physical activity and improving health.

Dog walking has been identified as a simple way of promoting physical activity [7–9]. Dog owners walk more often and are more physically active than non-dog owners [10]. This association has been observed in adults [11,12], adolescents and children [13–15], and in groups with potential limited mobility such as older adults [16–18] and people with a chronic disease [19]. Consequently, dog walking may lead to better health over time, with benefits ranging from improved wellbeing [20] to fewer doctor visits [21] and a lower risk of cardiovascular disease and mortality [22].

Aspects of the built environment also seem to influence dog walking behavior [9]. Supportive environments, such as parks, are associated with higher physical activity levels of dog owners and are important for promoting dog walking [8,9]. Specifically, better park access and park quality (e.g. presence of dog litter bags, water sources) were related to dog walking [9,23,24]. Parks are important for facilitating dog walking because dog walking often takes place in parks around an owner's residence [25]. Parks also provide an opportunity for nature contact. Spending time in natural outdoor environments (NOE), such as parks, has been associated with health benefits, for example through facilitating stress reduction, restoration, and social contact [26–28]. Dog owners walking their dog in NOE may benefit from the physical activity facilitated by owning a dog as well as time spent in nature. However, it is unclear whether dog owners receive additional health benefits associated with having access to NOE.

The aim of this study was to investigate the relationships between dog ownership, walking, NOE and health. We hypothesized that dog owners walk more, spend more time in NOE and are healthier than non-dog owners, and that health benefits are more apparent in dog owners with high exposure to NOE. We investigated the association between dog ownership, leisure time walking, time spent in NOE, and general and mental health status, and whether these associations differed for respondents with varying exposure to NOE.

METHOD

Study design and participants

This study analyzed data from the Positive Health Effects of the Natural Outdoor environment in Typical Populations in different regions in Europe (PHENOTYPE) project. Respondents were recruited from 30 different neighborhoods in Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania), and Stoke-on-Trent (United Kingdom) [29]. Neighborhoods were selected to maximize variability in access to NOE and socioeconomic status. A random sample of 30-35 adults aged 18-75 were invited to participate, resulting in approximately 1000 respondents per city. Data were collected using interview-administered questionnaires (except in Kaunas, where self-administered questionnaires were used) at respondents' residences during May-November 2013. The study was conducted in accordance with the Declaration of Helsinki. All respondents provided written informed consent and study protocols were approved by local ethical committees. Participant and stakeholder involvement and dissemination of results was organized in multiple ways through symposia, workshops, online media channels and newsletters.

Data

Dog ownership

Dog ownership was assessed using the question: "Do you own a dog" (yes; no).

Leisure time walking

Walking in leisure time was assessed by the following questions: "When thinking about a normal week in the past month how many days per week do you walk in your leisure time" and "How much time (minutes) per day do you spend walking in your leisure time". These items were derived from the short questionnaire to assess health-enhancing physical activity (SQUASH) [30]. The SQUASH is a valid measure of physical activity [30,31]. Duration and frequency of walking was multiplied to create a composite variable of minutes per week of leisure time walking. This composite variable was then dichotomized using the median (120 minutes/week) as a cut point. City-specific cut points were made for city-specific analyses (Barcelona: 120 min/week; Doetinchem: 120 min/week; Kaunas: 240 min/week; and Stoke-on-Trent: 20 min/week).

Time spent in NOE

Time spent in NOE was assessed using two questions: “How often did you visit/go in the last 4 weeks on purpose to green or blue space near your home?” (5-point response scale ranging from ‘never’ (1) to ‘almost daily’ (5)); and “How much time did you spend in a green or blue space near your home?” (4-point response scale ranging from <1 h (1) to 6–10 h (4)). A composite variable was created to determine the amount of time (frequency of visits multiplied by average duration per visit) respondents spent in NOE near home per month. As frequency and duration were assessed with questions with categorical response scales, the central value of each answer category for frequency (e.g. <1 times/month was coded as 0.5 times/month) were multiplied with central value of each answer category for duration (e.g. <1 h/month was coded as 0.5 h/month). The composite variable was then dichotomized using the median (4 hours/month) as a cut point. City-specific cut points were made for city-specific analyses (Barcelona: 3.75 h/month; Doetinchem: 10 h/month; Kaunas: 4 h/month; and Stoke-on-Trent: 1 h/month).

General health status

General health status was assessed using the question: “In general what would you say your health is?” (5 point response scale: excellent to poor), which was derived from the Medical Outcome Study Short Form (SF-36) [32]. Scores were dichotomized into “fair or poor” (0) and “excellent, very good, and good” (1). This single question has been found to be associated with poor health outcomes in the general population [33,34].

Mental health

Mental health was assessed using the SF-36 mental health subscale, including five items (e.g. nervousness, depression), and is a valid and reliable measure of mental health [35]. Respondents rated the occurrence of symptoms in the past four weeks on a 6-point scale ranging from “all of the time” (1) to “none of the time” (6). A sum score was calculated and transformed into a scale ranging from 0 to 100 according to guidelines [32] with higher scores indicating better mental health. When ≥ 3 items were missing, respondents were excluded from the analyses, but when 1-2 items were missing, missing values were replaced by the average score of the other items. We did this for 17 respondents. Analyses including and excluding these 17 respondents did not alter the results.

Characterization of NOE

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3 *Residential surrounding greenness* was assessed using the normalized difference vegetation index
4 (NDVI). The NDVI is a measure of vegetation and represents the photosynthetic activity in an area
5 [36,37]. Healthy vegetation absorbs most visible light and reflects large parts of near-infrared light, while
6 sparse vegetation reflects more visible light and less near-infrared light. Based on this distinction a value
7 between -1 and +1 is calculated, with higher values indicating a higher density of green vegetation [37].
8 The NDVI was derived from Landsat 5 and 8 satellite images at a resolution of 30 m × 30 m on cloud-
9 free images within the greenest season (April to September) in the relevant period for this study (2011-
10 2013). Average NDVI values were calculated within (Euclidean) buffers of 100m, 300m, and 500m
11 around the residence, as used in previous research [38,39], and dichotomized using the median value.
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21 *Access to NOE* was estimated with land use maps from local sources in each city. Only NOE that were
22 publically available; suitable for physical activity; and at least 0.5 hectare (e.g. parks, semi-natural/natural
23 land, formal recreation grounds) or 0.25 hectare (natural/green corridors) were selected as these were
24 relevant for physical activity [36] and therefore potentially relevant in terms of the health benefits of NOE
25 for dog owners. Road network buffers were chosen over circular buffers in order to capture a more
26 realistic measure of NOE accessibility on foot [40], which may be most relevant to dog walking. We
27 furthermore used varying buffer sizes to obtain a better understanding of what distance to NOE is most
28 beneficial to health [41]. Using GIS we constructed three indicators: (1) the number of, and (2) the total
29 surface area NOE within road network buffers of 300m, 500m, and 1000m, and (3) the road network
30 distance to the nearest NOE, all dichotomized using the median values.
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39 Covariates and other variables

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41 Information about sociodemographic factors included sex, age, educational level (primary school or no
42 education; secondary school/ further education (up to 18 years); university degree or higher), household
43 composition (alone; with partner (without children); with children <12 yr old; with children >12 yr old;
44 and other), perceived income situation (cannot make ends meet; enough to get by; comfortable),
45 frequency of contact with family and/or friends ((almost daily; ≥1 per week; 1-3 per month or less), and
46 whether respondents feel part of a group of friends ((totally) agree; neutral, (totally) disagree). Home-
47 related factors included perceived safety of neighborhood NOE (very satisfied; satisfied; neutral;
48 dissatisfied; very dissatisfied), home ownership (yes; no), crowding index (rooms/person), housing type
49 (detached; semi-detached; flat; other), and yard access (yes; no). Health-related factors included disability
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3 restricting mobility (yes; no), one or more chronic diseases (yes; no), body mass index (based on self
4 reported height and weight: healthy weight ≤ 25 kg/m²; overweight 25-30 kg/m²; obese >30 kg/m²), and
5 smoking status (current; former; never). Neighborhood socioeconomic status (SES, low; intermediate;
6 high) was based on country-specific data (Barcelona: deprivation index based on census data 2001 [42];
7 Doetinchem: average monthly household income per 6-digit zip code level [43]; Kaunas: neighborhood
8 education level [44]; Stoke-on-Trent: English indices of deprivation 2010 [45]).
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16 17 Statistical analyses

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19 Equivalence tests were used to test for differences between dog owner and non-dog owner characteristics.
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21 To investigate the association between dog ownership, leisure time walking, time spent in NOE, and
22 general and mental health status, and whether these associations differed for respondents with varying
23 exposure to NOE, we investigated:
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- 27 1. The associations between dog ownership, leisure time walking, time spent in NOE, general
28 health status, and mental health.
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30 2. The associations specified at 1, including interaction terms between dog ownership and NOE
31 indicators, to investigate whether these associations differed for respondents with varying
32 exposure to NOE.
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34 3. The associations specified at 1, stratified by NOE exposure, when the interaction term (specified
35 at 2) had a p-value <0.05 , to investigate these associations for respondents with varying exposure
36 to NOE.
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42 Associations were estimated using multilevel analysis with a random intercept defined at the city and
43 neighborhood level. Models were adjusted for age, sex, education level, household composition,
44 perceived income situation, neighborhood SES, NOE safety, disability restricting mobility, and chronic
45 diseases and were selected because of an assumed relation with dog ownership, walking, NOE exposure
46 and health. The main associations (as specified at 1) were also estimated for the cities separately.
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48 Analyses were based on complete cases.
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54 Sensitivity analyses were undertaken to investigate whether adjustment for characteristics that were found
55 to differ between dog owners and non-dog owners, and that may relate to health, changed the
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3 associations. Models were additionally adjusted (separately and simultaneously) for smoking, BMI,
4 frequency of contact with family and/or friends, and whether respondents feel part of a group of friends.
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6 A second sensitivity analysis was undertaken to evaluate differences between time spent in NOE near
7 home, and in or near the city for associations specified at 2 and 3 by using two variables: time spent in
8 NOE in the city, and time spent in NOE near the city.
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11 RESULTS

12 Population characteristics

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15 Respondents were on average 51.4 (SD 15.9) years old and 54.9% was female. A total of 1109 (30.9%)
16 respondents were dog owners. Dog owners compared with non-dog owners were on average the same
17 age, had similar educational attainment but more were female (59.6% vs. 53.3%) and reported lower
18 perceived income security. Dog ownership varied across cities, with it being highest in Kaunas (41.1%)
19 and lowest in Doetinchem (16.5%). Dog owners walked more and spent more time in NOE compared
20 with non-dog owners. However, dog owners had a lower perceived general and mental health status
21 compared with non-dog owners. Dog owners also reported more frequently that physical constraints
22 restricted their mobility, had more often a chronic disease, and had higher BMI than non-dog owners
23 (Table 1).
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35 Dog ownership, leisure time walking, time spent in NOE and health

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38 Adjusted multilevel models showed that dog ownership was associated with increased odds of walking
39 ≥ 121 minutes per week (i.e. higher than the median amount of walking) (odds ratio (OR) = 2.13, 95%
40 confidence interval (CI) 1.82, 2.50) compared with non-dog owners. Dog ownership was also associated
41 with increased odds of spending ≥ 4 hours/month in NOE (i.e. higher than the median amount of time in
42 NOE) (OR= 2.42, 95% CI 2.05, 2.86) compared with non-dog owners. There were no differences in
43 general health status and mental health between dog owners and non-dog owners. City-specific analyses
44 showed similar results, with some exceptions: a positive association between dog ownership and general
45 health in Barcelona (OR=1.90, 95% CI 1.01, 3.56); a positive association between dog ownership and
46 mental health in Stoke-on-Trent (OR= 2.61, 95% CI 0.35, 4.86); but no association between dog
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3 ownership and time spent in NOE in Doetinchem. In Kaunas, there were no associations between leisure
4 time walking and time spent in NOE by dog ownership status (Table 2).

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7 (Table 2 here)

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9 Interactions between dog ownership and NOE

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12 We found indication for interaction between leisure time walking, dog ownership and number of NOE
13 (all buffer sizes). Stratified analyses showed that dog owners with the highest number of NOE around
14 their home had increased odds of performing ≥ 121 minutes per week of leisure time walking (i.e. higher
15 than the median amount of walking) (e.g. 1000m buffer: OR= 3.54, 95% CI 2.76, 4.54) compared with
16 non-dog owners. For those with a lower number of NOE, dog ownership was also associated with more
17 leisure time walking, but odds ratios were smaller (e.g. 1000m buffer: OR= 1.41, 95% CI 1.14, 1.75).
18 Similar results were observed for those with a shorter distance to the nearest NOE, and for those with a
19 higher amount of surrounding greenness within 500m around home (Table 3).
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27 For time spent in NOE, there was indication of interaction between dog ownership and number of NOE
28 within 500m and 1000m of home. Stratified analyses showed that dog owners with a higher number of
29 NOE spent more time in NOE (i.e. ≥ 4 hours/month or higher than the median amount of time in NOE)
30 compared with non-dog owners (e.g. 1000m buffer: OR= 4.31, 95% CI 3.31, 5.63). In comparison, dog
31 owners with a lower number of NOE near home also spent more time in NOE compared with non-dog
32 owners, but the odds ratios were smaller (e.g. 1000m buffer: OR= 1.60, 95% CI 1.29, 1.99) (Table 3).
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39 There was indication for interaction between dog ownership and NOE exposure indicators in relation to
40 mental health for the number and area of NOE within 1000m of home and for NDVI within 300m of
41 home. Stratified analyses showed that dog owners with the highest number of NOE within 1000m of
42 home had better mental health compared with non-dog owners ($\beta = 2.70$, 95% CI 1.08, 4.32), but showed
43 no association for those with a below median number of NOE. Dog ownership was associated with better
44 mental health for those with a lower amount of surrounding greenness within 300m around home ($\beta =$
45 1.79, 95% CI 0.06, 3.52), but not for those with a higher amount of surrounding greenness (Table 3).
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51 There were no associations between dog ownership and mental health, stratified by area of NOE within
52 1000m of home. Finally, there was no indication for interaction between dog ownership and NOE
53 exposure indicators in relation to general health status.
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8 Sensitivity analysis
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10 Additional adjusted for smoking, BMI, frequency of contact with family and/or friends, and whether
11 respondents feel part of a group of friends, did not change the results (results available upon request).
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13 Furthermore, there was no indication for interaction between dog ownership and time spent in NOE in
14 and near the city (results available upon request).
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21 DISCUSSION 22

23 Having a dog was associated with more leisure time walking and time spent in NOE near home compared
24 with not having a dog. Moreover, the differences in walking and time spent in NOE between dog owners
25 and non-dog owners were larger when there were more NOE near home. There was no consistent
26 evidence for an association between dog ownership and general and mental health status. Only dog
27 owners from Stoke-on-Trent had better mental health compared with non-dog owners, and dog owners
28 from Barcelona had better general health compared to non-dog owners.
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35 Prior studies have also observed links between NOE, dog ownership and physical activity. In support of
36 our findings, a UK study of older adults reported that neighborhood greenness was associated with a
37 smaller decline in physical activity over time, and that dog walking explained up to 50% of the variance
38 in the relationship between greenness and outdoor physical activity [46]. Our findings were also
39 consistent with a Danish study that found that dog ownership was a major determinant of park visits,
40 especially those parks closest to the residence [25]. Our study adds to the evidence base by including
41 multiple exposure indicators of NOE which enabled studying multiple exposure indicators of NOE
42 simultaneously, and could help understand what metric best predicts the health benefits associated with
43 NOE [26,27,29]. We found that dog owners spent more time in NOE than non-dog owners, but dog
44 ownership was not consistently related to mental or general health status. Dog ownership was only related
45 to better general or mental health in Barcelona and Stoke-on-Trent, the two cities where respondents were
46 the least active and spent the least time in NOE, and may indicate that health benefits of dog ownership
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3 exist when walking and time spent in NOE is low to begin with. Because we found no consistent evidence
4 for health benefits for dog owners with better availability of NOE, future studies could also investigate
5 subjective indicators of NOE, including satisfaction and importance, and neighborhood aesthetics [47].
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9 Although the cross-sectional nature of our study does not allow for understanding the longitudinal effects
10 of dog ownership on health, it is possible that people with physical constraints and chronic diseases more
11 often decide to have a dog, for example following doctor's advice, in order to stay mobile [22]. Similarly,
12 another study reported that dog owners more often had asthma, and a higher BMI compared with non-dog
13 owners [48]. Furthermore, an Australian study found that although pet ownership was associated with
14 higher levels of physical activity, it was also associated with higher BMI, higher diastolic blood pressure,
15 and smoking [49]. We found that despite being less healthy, dog owners engaged in about twice as much
16 leisure time walking than non-dog owners. We hypothesize that the extra physical activity facilitated by
17 dog walking may offset some of the other negative health risk factors dog owners have, and could
18 eventually yield longer term health benefits. This may especially occur when there is access to NOE and
19 the residential environment promotes walking.
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29 Limitations of this study include the lack of information about the dog owner's level of attachment to
30 their dog, the duration of dog ownership, and if the respondent was the primary carer of the dog. We
31 further did not know if the time spent in NOE and leisure time walking was undertaken together with the
32 dog, and whether time spent in NOE was time spent walking. Future research should measure specific
33 aspects of dog ownership and should use measures of behavior such as time spent in NOE with and
34 without dog and leisure time walking undertaken with and without the dog. A limitation of self-reporting
35 walking habits is potential overstatement of the amount of walking. Finally, we cannot establish the
36 direction of the observed relationships because of the cross-sectional study design. For example, people
37 who are already physically active and visit NOE may decide to get a dog, instead of dogs motivating their
38 owners to walk and visit NOE more. Strengths include the multi-city approach, which revealed
39 differences between cities concerning dog ownership and health. It is also one of the first studies from
40 mainland Europe, since the majority of research has been carried out in North America, Australia, and in
41 the UK. Finally, our measure of access to NOE was specific to environments that were suitable for
42 physical activity. We also used road network buffers over circular buffers which better capture people's
43 walking behavior; and we used varying buffer sizes to obtain a better understanding of what distance to
44 NOE is most beneficial to health [41].
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Conclusions

Dog owners performed more leisure time walking and spent more time in NOE compared with non-dog owners, especially when the number of NOE around the home was greater. There was no consistent relationship between dog ownership and better general or mental health status. In a largely physically inactive society where many people remain indoors, dog walking in parks or other NOE may be an opportunity to engage people in walking behavior as a path towards better health.

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Tables.

Table 1. Population characteristics by dog-ownership

	Total n=3586	Non-dog- owner n=2478	Dog owner n=1108	p-value*
Age, mean (SD)	51.4 (15.9)	51.3 (15.9)	51.7 (16.0)	.440
Sex, n (females %)	1967 (54.9)	1314 (53.0)	653 (58.9)	<.001
Household composition, n (%)				<.001
<i>alone</i>	614 (17.1)	461 (18.6)	153 (13.8)	
<i>with partner (without children)</i>	1239 (34.5)	864 (34.9)	375 (33.8)	
<i>with children <12 yr old</i>	535 (14.9)	383 (15.5)	152 (13.7)	
<i>with children >12 yr old</i>	602 (16.8)	368 (14.9)	234 (21.2)	
<i>other</i>	597 (16.6)	402 (16.2)	195 (17.6)	
City, n (%)				<.001
<i>Barcelona</i>	979 (27.3)	790 (31.9)	189 (17.1)	
<i>Doetinchem</i>	851 (23.7)	668 (27.0)	183 (16.5)	
<i>Kaunas</i>	892 (24.9)	436 (17.6)	456 (41.1)	
<i>Stoke-on-Trent</i>	864 (24.1)	584 (23.6)	280 (25.3)	
Education, n (%)				.511
<i>low</i>	251 (7.0)	163 (6.6)	88 (7.9)	
<i>medium</i>	1568 (43.7)	1087 (43.9)	481 (43.5)	
<i>high</i>	1767 (49.3)	1228 (49.6)	539 (48.6)	
Perceived income situation, n (%)				<.001
<i>cannot make ends meet</i>	385 (10.7)	276 (11.1)	109 (9.8)	
<i>enough to get by</i>	1800 (50.2)	1165 (47.0)	635 (57.3)	
<i>comfortable</i>	1401 (39.1)	1037 (41.9)	364 (32.9)	
Home ownership, n (% yes)	2040 (57.4)	1319 (53.8)	721 (65.4)	<.001
Crowding index (rooms/person), median (IQR)	1.5 (2)	1.7 (1.5)	1.5 (1)	<.001
Housing type, n (%)				<.001

<i>detached</i>	888 (24.8)	630 (25.4)	258 (23.3)	
<i>semi-detached</i>	1064 (29.7)	656 (26.5)	408 (36.8)	
<i>flat</i>	1548 (43.2)	1137 (45.9)	411 (37.1)	
<i>other</i>	82 (2.3)	53 (2.1)	29 (2.6)	
Yard access, n (% yes)	1875 (53.4)	1239 (50.8)	636 (59.4)	<.001
General health, n (%)				<.001
<i>Excellent, (very) good</i>	2662 (74.2)	1939 (78.3)	723 (65.2)	
<i>(Very) Bad</i>	924 (25.8)	539 (21.8)	385 (34.8)	
Mental health (SF-36), mean (SD)	73.5 (16.3)	73.9 (16.2)	72.5 (16.3)	.007
Weight status (BMI categories), n (%)				<.001
<i>healthy weight</i>	1610 (44.9)	1165 (47.0)	445 (40.2)	
<i>overweight</i>	1192 (33.2)	819 (33.1)	373 (33.6)	
<i>obese</i>	784 (21.9)	494 (19.9)	290 (26.2)	
Physical constraint restricting mobility, n (%)	1003 (25.4)	536 (19.9)	467 (37.3)	<.001
One or more chronic diseases, n (%)	1313 (36.6)	860 (34.7)	453 (40.9)	<.001
Minutes/week walking (leisure), median (IQR)	120 (300)	90 (240)	180 (420)	<.001
Smoking, n (%)				.016
<i>current</i>	733 (20.5)	478 (19.3)	255 (23.0)	
<i>former</i>	1008 (28.1)	724 (29.2)	284 (25.6)	
<i>never</i>	1843 (51.4)	1275 (51.5)	568 (51.3)	
Frequency of contact with family and/or friends, n (%)				.256
<i>(almost) daily</i>	2135 (59.5)	1470 (59.3)	665 (60.0)	
<i>≥1 per week</i>	1114 (31.1)	781 (31.1)	333 (30.0)	
<i>1-3 per month or less</i>	392 (9.4)	227 (9.2)	111 (10.0)	
Feeling part of a group of friends, n %				<.001
<i>(totally) agree</i>	2414 (67.5)	1754 (70.9)	660 (59.7)	
<i>neutral, (totally) disagree</i>	1165 (32.5)	719 (29.1)	446 (40.3)	

Perceived safety of NOE in NBH, n (%)				.012
<i>(very) satisfied</i>	2123 (59.2)	1486 (60.0)	637 (57.5)	
<i>neutral</i>	776 (21.6)	542 (21.9)	234 (21.1)	
<i>(very) dissatisfied</i>	687 (19.2)	450 (18.2)	237 (21.4)	
NBH SES, n (%)				.425
<i>low</i>	1131 (31.5)	791 (31.9)	340 (30.7)	
<i>medium</i>	1379 (38.4)	938 (37.9)	441 (39.8)	
<i>high</i>	1076 (30.0)	749 (30.2)	327 (29.5)	
Hours spent in NOE near home in last 4 wks, median (IQR)	4 (11.8)	3.75 (10)	10 (29.3)	<.001
Average NDVI in 100m buffer, median (IQR)	0.46 (0.16)	0.44 (0.28)	0.50 (0.16)	<.001
Average NDVI in 300m buffer, median (IQR)	0.49 (0.23)	0.47 (0.30)	0.51 (0.13)	<.001
Average NDVI in 500m buffer, median (IQR)	0.49 (0.23)	0.48 (0.31)	0.51 (0.11)	<.001
Distance to nearest NOE (m), median (IQR)	161.0 (214)	155.7 (205.6)	172.4 (232.4)	<.001
Number of NOE in 300m NWB, median (IQR)	1 (1)	1 (2)	1 (2)	<.001
Number of NOE in 500m NWB, median (IQR)	1 (1)	3 (3)	3 (3)	<.001
Number of NOE in 1000m NWB, median (IQR)	10 (10)	11 (10)	8 (10)	<.001
Area of NOE in 300m NWB (m ²), median (IQR)	38,013 (136,092)	36,007 (132,239)	41,241 (154,377)	.581
Area of NOE in 500m NWB (m ²), median (IQR)	140,281 (286,917)	137,862 (261,453)	150,758 (402,966)	.024
Area of NOE in 1000m NWB (m ²), median (IQR)	588,516 (975,551)	557,191 (890,303)	720,366 (239,293)	<.001

NOE= natural outdoor environments; NBH= neighborhood; NWB= network buffer; IQR= interquartile range; SD= standard deviation; BMI= body mass index; SES= socioeconomic status. * based on t-tests, Chi-square, Kruskal-Wallis, and rank-sum tests.

Table 2. Associations between dog-ownership, leisure time walking, time spent in NOE near the home, general health status and mental health.

	Leisure time walking above median (reference: below median)	Time spent in NOE near home above median (reference: below median)	General health, excellent, (very) good (reference: fair, poor) OR (95% CI)	Mental health (scale 0-100, higher is better) β (95% CI)
Dog ownership (vs. not)	OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)
Total	2.13 (1.82; 2.50) n=3586	2.42 (2.05; 2.86) n=3530	1.03 (0.82; 1.29) n=3586	0.42 (-0.71; 1.55) n=3584
Barcelona	1.46 (1.03; 2.08) n=979	2.14 (1.47; 3.13) n=978	1.90 (1.01; 3.56) n=979	0.13 (-2.29; 2.55) n=979
Doetinchem	7.97 (5.18; 12.25) n=851	1.18 (0.80; 1.73) n=846	0.89 (0.37; 2.17) n=851	1.61 (-0.55; 3.78) n=849
Kaunas	1.05 (0.79; 1.39) n=892	1.26 (0.93; 1.69) n=844	0.71 (0.50; 1.00) n=892	-2.17 (-4.40; 0.06) n=892
Stoke-on-Trent	2.01 (1.44; 2.79) n=864	2.31 (1.63; 3.27) n=862	0.89 (0.57; 1.37) n=864	2.61 (0.35; 4.86) n=864

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval

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3 *Analytical method: mixed models with random intercept for cities* and neighborhoods and adjusted for*
4 *age, sex, education, neighborhood SES, household composition, perceived income situation, perceived*
5 *NOE safety, physical constraint restricting mobility, and chronic diseases.*

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8 **for analyses with total sample. Analyses were based on complete cases.*
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Table 3. Interactions between dog-ownership and the NOE and the relation with leisure time walking, time spent in NOE near the home, general health and mental health.

	Leisure time walking above median (reference: below median)	Time spent in NOE near home above median (reference: below median)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
Dog ownership (vs. not)	OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)
300m	$p_{\text{interaction}} .007$	$p_{\text{interaction}} .101$	$p_{\text{interaction}} .700$	$p_{\text{interaction}} .335$
lowest	1.75 (1.43; 2.14) n=2082	NA	NA	NA
highest	2.99 (2.30; 3.88) n=1504	NA	NA	NA
500m	$p_{\text{interaction}} .006$	$p_{\text{interaction}} .015$	$p_{\text{interaction}} .504$	$p_{\text{interaction}} .349$
lowest	1.70 (1.38; 2.09) n=1944	2.01 (1.62; 2.49) n=1902	NA	NA
highest	2.97 (2.31; 3.83) n=1642	3.36 (2.58; 4.38) n=1628	NA	NA
1000m	$p_{\text{interaction}} <.001$	$p_{\text{interaction}} <.001$	$p_{\text{interaction}} .714$	$p_{\text{interaction}} <.001$
lowest	1.41 (1.14; 1.75) n=1820	1.60 (1.29; 1.99) n=1773	NA	-1.45 (-3.02, 0.13) n=1819
highest	3.54 (2.76; ...)	4.31 (3.31; ...)	NA	2.70 (1.08, ...)

		4.54)	5.63)	4.32)
		n=1766	n=1757	n=1765
	300m	p _{interaction} .407	p _{interaction} .224	p _{interaction} .286
	lowest	NA	NA	NA
	highest	NA	NA	NA
	500m	p _{interaction} .071	p _{interaction} .715	p _{interaction} .897
	lowest	NA	NA	NA
	highest	NA	NA	NA
Area of NOE	1000m	p _{interaction} .114	p _{interaction} .155	p _{interaction} .607
	lowest	NA	NA	NA
				-0.75 (-2.42,
				0.92)
				n=1787
	highest	NA	NA	NA
				1.33 (-0.20,
				2.85)
				n=1797
	100m	p _{interaction} .820	p _{interaction} .566	p _{interaction} .989
	lowest	NA	NA	NA
	highest	NA	NA	NA
	300m	p _{interaction} .284	p _{interaction} .895	p _{interaction} .770
	lowest	NA	NA	NA
				1.79 (0.06,
				3.52)
				n=1786
Surrounding greenness (NDVI)	highest	NA	NA	NA
				-0.93 (-2.41,
				0.56)
				n=1798
	500m	p _{interaction} .014	p _{interaction} .248	p _{interaction} .735
	lowest	1.72 (1.34;	NA	NA
		2.22)		NA
		n=1765		
	highest	2.50 (2.03;	NA	NA
				NA

		3.09)			
		n=1821			
		$p_{\text{interaction}} .043$	$p_{\text{interaction}} .070$	$p_{\text{interaction}} 0.520$	$p_{\text{interaction}} .725$
	closest	2.57 (2.04;	NA	NA	NA
		3.23)			
	Distance to	n=1801			
	nearest NOE				
	furthest	1.84 (1.48;	NA	NA	NA
		2.29)			
		n=1785			
		$p_{\text{interaction}} .401$	NA	$p_{\text{interaction}} .493$	$p_{\text{interaction}} .150$
	Time spent in				
	NOE near home				
	lowest	NA	NA	NA	NA
	highest	NA	NA	NA	NA

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval; NA= not applicable;

NDVI= normalized difference vegetation index. *Analytical method: mixed models with random intercept for cities and neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.*

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

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

		cases and controls was addressed	
		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	
		(e) Describe any sensitivity analyses	10-11
Results			Appears in manuscript on page
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	-
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	-
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	n.a.
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	n.a.
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	n.a.
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	Table 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Tables, 11-12
		(b) Report category boundaries when continuous variables were categorized	Tables, 7-10
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n.a.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Tables, 12-13
Discussion			
Key results	18	Summarise key results with reference to study objectives	13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	13-14
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	4-5

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

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

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Dog ownership, the natural outdoor environment and health: a cross-sectional study

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Manuscripts

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5 Dog ownership, the natural outdoor environment and health: a cross-sectional study
67
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Abstract

Objectives

Dog owners walking their dog in natural outdoor environments (NOE) may benefit from the physical activity facilitated by dog walking and from time spent in nature. However, it is unclear whether dog owners receive additional health benefits associated with having access to NOE above the physical activity benefit of walking with their dog. We investigated associations between dog ownership, walking, time spent in NOE, and health and whether these associations differed among those with good and poor access to NOE and those living in green and less green areas.

Design

Cross-sectional study

Setting

The Positive Health Effects of the Natural Outdoor Environment in Typical Populations in Different Regions in Europe (PHENOTYPE) project.

Participants

n=3586 adults from Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania), and Stoke-on-Trent (United Kingdom).

Data collection and analysis

We calculated access to NOE with land maps and residential surrounding greenness with satellite data. Leisure time walking, time spent in NOE, and general and mental health status were measured using validated questionnaires. Associations were estimated using multilevel analysis with a random intercept defined at the neighborhood level.

Results

Dog ownership was associated with higher rates of leisure time walking and time spending in NOE (incidence rate ratio 1.65, 95% CI 1.65, 1.66 and 1.48, 95% CI 1.45, 1.51 respectively). These

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3 associations were stronger in those with better access to NOE and in greener areas. No consistent
4
5 associations were found between dog ownership and perceived general or mental health status.
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8 Conclusions

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10 Compared with non-dog owners, dog owners walked more and spent more time in NOE, especially in
11
12 those with access to NOE and in greener areas. The health implications of these relationships should be
13
14 further investigated. In a largely physically inactive society, dog walking in NOE may be a simple way of
15
16 promoting physical activity and health.
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- 22 • Strengths and limitations This is one of the first studies from mainland Europe, and the multi-city
23 approach revealed differences between cities concerning dog ownership and health.
- 24 • The assessment of access to natural outdoor environments suitable for physical activity using
25 road network buffers was chosen to optimally capture the relation with people's walking
26
27 behavior.
28
29
- 30 • The use of multiple exposure indicators of natural outdoor environments enabled studying these
31
32 exposure indicators simultaneously, and could help understand what metric best predicts the
33
34 health benefits associated with natural outdoor environments.
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- 37 • We cannot establish the direction of the observed relationships because of the cross-sectional
38
39 study design.
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- 44 • We had no detailed information about dog ownership (e.g. level of attachment, duration of dog
45
46 ownership, primary caretaker) and we did not know if the time spent in natural outdoor
47
48 environments and leisure time walking was undertaken together with the dog.
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55 Competing interests

56
57
58 None declared
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Funding

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Author's Contributions

WLZ conducted the analyses. WLZ, HC and JL drafted the manuscript. MTM, MC, MB, JM, CG, HK, WWV, SA, RG, MJN were involved in the design of and data acquisition in the PHENOTYPE study. All authors provided input on the manuscript and agreed with the final version.

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Data sharing statement

Additional data are available upon request from the corresponding author (WLZ:

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INTRODUCTION

In an urbanized world, where people spend the majority of their time indoors [1], physical inactivity is a major public health problem [2]. It not only leads to adverse health effects but it is also a large economic burden for society [3]. Physical activity behavior is influenced by the built environment [4]. Aspects of the built environment such as the availability of parks are associated with increased physical activity, especially walking [5,6]. It is important to identify sustainable built environment interventions for increasing physical activity and improving health.

Dog walking has been identified as a simple way of promoting physical activity [7–10]. There is strong evidence to suggest that dog owners walk more often and are more physically active than non-dog owners [10–12]. This association has been observed in adults [13,14], adolescents and children [15–17], in groups with potential limited mobility such as older adults [18–20] and in people with a chronic disease [21]. Consequently, dog walking may lead to better health over time, with benefits ranging from improved wellbeing [22] to fewer doctor visits [23] and a lower risk of cardiovascular disease and mortality [24].

However, not all studies show health benefits of dog ownership [25–27] and a large proportion of dog owners do not walk their dog [28,29]. Of the various factors that influence dog walking behavior, aspects of the built environment seem to be among them [9]. Supportive environments, such as neighborhoods with parks and other types of green infrastructure, are associated with higher physical activity levels of dog owners and are important for promoting dog walking [8,9,30]. Specifically, better park access and park quality (e.g. presence of dog litter bags, water sources) were related to dog walking [9,31,32]. Not all dog owners have access to parks thus improving access to parks in residential areas could be important for facilitating dog walking, especially since local parks are a common place for dog walking [33]. Parks also provide an opportunity for nature contact. Spending time in natural outdoor environments (NOE), such as parks, has been associated with health benefits, for example through facilitating stress reduction, restoration, and social contact [34–36]. Dog owners walking their dog in NOE may benefit from the physical activity facilitated by owning a dog as well as time spent in nature. However, it is unclear whether dog owners receive additional health benefits associated with having access to NOE. According to the theories of health behavior [37] and the social ecological framework [38], identifying the environmental factors that influence health outcomes (e.g. access to NOE) could lead to potential intervention strategies that could eventually improve health.

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3 The aim of this study was to investigate the relationships between dog ownership, walking, the NOE and
4 health. In line with above-mentioned studies and health behavior theories, we hypothesized that dog
5 owners walk more, spend more time in NOE and are healthier than non-dog owners, and that the health
6 benefits are more apparent in dog owners within green neighborhoods and with access to NOE compared
7 to those in less green areas and with poor NOE access. We therefore investigated the associations
8 between dog ownership, leisure time walking, time spent in NOE, and general and mental health status,
9 and whether these associations differed among those with good and poor access to NOE and those living
10 in green and less green areas.
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19 METHOD

20 Study design and participants

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22 This study analyzed data from the Positive Health Effects of the Natural Outdoor environment in Typical
23 Populations in different regions in Europe (PHENOTYPE) project. Respondents were recruited from 30
24 different neighborhoods in Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania), and
25 Stoke-on-Trent (United Kingdom) [39]. Neighborhoods were selected to maximize variability in access to
26 NOE and socioeconomic status. In order to arrive at a final sample of approximately 1000 respondents
27 per city, a random sample of 30 to 35 addresses per neighborhood were mailed with a letter explaining the
28 purpose of the project after which they were visited by interviewers. In Doetinchem, persons were asked
29 to send back an answer card to indicate their willingness to participate before they were visited by the
30 interviewers; and in Kaunas, persons were approached by mail to fill out postal questionnaires.
31 Respondents needed to have an age between 18 and 75 years and to be able to speak the local language.
32 Data were collected using interview-administered questionnaires (except in Kaunas, where self-
33 administered questionnaires were used) at respondents' residences during May-November 2013. The
34 study was conducted in accordance with the Declaration of Helsinki. All respondents provided written
35 informed consent and study protocols were approved by local ethical committees.
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51 Patient and Public Involvement

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53 Participant and stakeholder involvement and dissemination of results was organized in multiple ways
54 through symposia, workshops, online media channels and newsletters.
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60 Data

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3 Explanatory variables

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5 Dog ownership

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7 Dog ownership was assessed using the question: “Do you own a dog” (yes; no).
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11 *Access to NOE* was estimated with land use maps from local sources in each city. Only NOE that were
12 publically available; suitable for physical activity; and at least 0.5 hectare (e.g. parks, semi-natural/natural
13 land, formal recreation grounds) or 0.25 hectare (natural/green corridors) were selected as these were
14 relevant for physical activity [40] and therefore potentially relevant in terms of the health benefits of NOE
15 for dog owners. Road network buffers were chosen over circular buffers in order to capture a more
16 realistic measure of NOE accessibility on foot [41], which may be most relevant to dog walking. We
17 furthermore used three predetermined buffer sizes to obtain a better understanding of what distance to
18 NOE is most beneficial to health [42]. Using GIS we constructed three indicators: (1) the number of, and
19 (2) the total surface area NOE within road network buffers of 300m, 500m, and 1000m, and (3) the road
20 network distance to the nearest NOE (Figure 1). The number of and area of NOE were dichotomized
21 using the city-specific median values. Distance to nearest NOE was dichotomized using a 300m cut off
22 according to guidelines [43].
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35 *Residential surrounding greenness* was assessed using the normalized difference vegetation index
36 (NDVI). The NDVI is a measure of vegetation and represents the photosynthetic activity in an area
37 [40,44]. Healthy vegetation absorbs most visible light and reflects large parts of near-infrared light, while
38 sparse vegetation reflects more visible light and less near-infrared light. Based on this distinction a value
39 between -1 and +1 is calculated, with higher values indicating a higher density of green vegetation [44].
40 The NDVI was derived from Landsat 5 and 8 satellite images at a resolution of 30 m × 30 m on cloud-
41 free images within the greenest season (April to September) in the relevant period for this study (2011-
42 2013). Average NDVI values were calculated within (Euclidean) buffers of 100m, 300m, and 500m
43 around the residence, as used in previous research [45,46], and dichotomized using the city-specific
44 median value.
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55 (Figure 1 here)

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58 Figure 1. Example of different buffer types and the distance to natural outdoor environments from a
59 residential address.
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Outcome variables

Leisure time walking

Walking in leisure time was assessed by the following questions: “When thinking about a normal week in the past month how many days per week do you walk in your leisure time” and “How much time (minutes) per day do you spend walking in your leisure time”. These items were derived from the short questionnaire to assess health-enhancing physical activity (SQUASH) [47]. The SQUASH is a valid measure of physical activity [47,48]. Duration and frequency of walking was multiplied to create a composite variable of minutes per week of leisure time walking.

Time spent in NOE

NOE were defined as all public and private outdoor spaces that contain ‘green’ and/or ‘blue’ natural elements such as street trees, forests, city parks and natural parks/reserves, and also included all types of waterbodies such as canals, ponds, creeks, rivers, beaches. Time spent in NOE was assessed using two questions: “How often did you visit/go in the last 4 weeks on purpose to green or blue space near your home?” (5-point response scale ranging from ‘never’ (1) to ‘almost daily’ (5)); and “How much time did you spend in a green or blue space near your home?” (4-point response scale ranging from <1 h (1) to 6–10 h (4)). A composite variable was created to determine the amount of time (frequency of visits multiplied by average duration per visit) respondents spent in NOE near home per month. As frequency and duration were assessed with questions with categorical response scales, the central value of each answer category for frequency were multiplied with central value of each answer category for duration (e.g. 3-5 h/month was coded as 4 h/month).

General health status

General health status was assessed using the question: “In general what would you say your health is?” (5 point response scale: excellent to poor), which was derived from the Medical Outcome Study Short Form (SF-36) [49]. Scores were dichotomized into “fair or poor” (0) and “excellent, very good, and good” (1). This single question has been found to be associated with poor health outcomes in the general population [50,51].

Mental health

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3 Mental health was assessed using the Short Form Health Survey (SF-36) mental health subscale,
4 including five items (e.g. nervousness, depression), and is a valid and reliable measure of mental health
5 [52]. Respondents rated the occurrence of symptoms in the past four weeks on a 6-point scale ranging
6 from “all of the time” (1) to “none of the time” (6). A sum score was calculated and transformed into a
7 scale ranging from 0 to 100 according to guidelines [49] with higher scores indicating better mental
8 health. When ≥ 3 items were missing, respondents were excluded from the analyses, but when 1-2 items
9 were missing, missing values were replaced by the average score of the other items. We did this for 17
10 respondents. Analyses including and excluding these 17 respondents did not alter the results.
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19 Covariates and other variables

20 Information about sociodemographic factors included sex, age, educational level (primary school or no
21 education; secondary school/ further education (up to 18 years); university degree or higher), household
22 composition (alone; with partner (without children); with children <12 yr old; with children >12 yr old;
23 and other), perceived income situation (cannot make ends meet; enough to get by; comfortable),
24 frequency of contact with family and/or friends ((almost daily; ≥ 1 per week; 1-3 per month or less), and
25 whether respondents feel part of a group of friends ((totally) agree; neutral, (totally) disagree). We also
26 included perceived safety of neighborhood NOE (very satisfied; satisfied; neutral; dissatisfied; very
27 dissatisfied). Health-related factors included disability restricting mobility (yes; no), one or more chronic
28 diseases (yes; no), body mass index (based on self reported height and weight: healthy weight ≤ 25 kg/m²;
29 overweight 25-30 kg/m²; obese >30 kg/m²), and smoking status (current; former; never). Neighborhood
30 socioeconomic status (SES, low; intermediate; high) was based on country-specific data (Barcelona:
31 deprivation index based on census data 2001 [53]; Doetinchem: average monthly household income per
32 6-digit zip code level [54]; Kaunas: neighborhood education level [55]; Stoke-on-Trent: English indices
33 of deprivation 2010 [56]).
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51 Statistical analyses

52 Equivalence tests with Benjamini-Hochberg adjustments for false discovery rates (5%) [57] were used to
53 test for differences between dog owner and non-dog owner characteristics. To investigate the association
54 between dog ownership, leisure time walking, time spent in NOE, and general and mental health status,
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3 and whether these associations differed for respondents with good/poor access to NOE and high/low
4 residential surrounding greenness, we investigated:

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7 1. The associations between dog ownership, leisure time walking, time spent in NOE, general
8 health status, and mental health.
- 9
10 2. The associations specified at 1, stratified by NOE access (good and poor) and by residential
11 surrounding greenness (high and low) to investigate whether the associations between dog
12 ownership and the outcomes differ in these subgroups.
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18 Associations were estimated using multilevel analysis with a random intercept defined at the
19 neighborhood level. Associations with leisure time walking and time spent in NOE were estimated with
20 Poisson regression which is used to model count variables; associations with general health status were
21 estimated with logistic regression because of the dichotomous nature of the data; and since mental health
22 scores were normally distributed, associations were estimated with linear regression. Models were
23 adjusted for age, sex, education level, household composition, perceived income situation, neighborhood
24 SES, NOE safety, disability restricting mobility, and chronic diseases and were selected because of an
25 assumed relation with dog ownership, walking, time spent in NOE and health. The main associations (as
26 specified at 1) were also estimated for the cities separately. Stratified analyses by access to NOE and
27 residential surrounding greenness were undertaken with indicators in all buffer sizes, but the 500m buffer
28 was reported in the main table and the remaining buffer sizes in the Supplement. Analyses were based on
29 complete cases (missing data differed by outcome and ranged between n=360 and 416). All analyses were
30 performed in STATA 14.2 [58].
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44 Sensitivity analyses were undertaken to investigate whether additional adjustment for covariates changed
45 the associations. Additional adjustments were carried out for characteristics that were found to differ
46 between dog owners and non-dog owners and that may relate to health (smoking and BMI), or that have
47 been found to be mediators of the dog ownership-health relationship (frequency of contact with family
48 and/or friends, and whether respondents feel part of a group of friends) [59,60].
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RESULTS

Population characteristics

Respondents were on average 51.4 (SD 15.9) years old and 54.9% were female. A total of 1109 (30.9%) respondents were dog owners. Dog owners compared with non-dog owners were on average the same age, had similar educational attainment but more were female (59.6% vs. 53.3%) and reported lower perceived income security. Dog ownership varied across cities, with it being highest in Kaunas (41.1%) and lowest in Doetinchem (16.5%). Dog owners walked more and spent more time in NOE compared with non-dog owners. However, dog owners had a lower perceived general and mental health status compared with non-dog owners. Dog owners also reported more frequently that physical constraints restricted their mobility, had more often a chronic disease, and had higher BMI than non-dog owners (Table 1).

(Table 1 here)

Dog ownership, leisure time walking, time spent in NOE and health

Adjusted multilevel models showed that dog ownership was associated with increased rates of leisure time walking (incidence rate ratio [IRR]= 1.65, 95% CI 1.65, 1.66) compared with non-dog owners. Dog ownership was also associated with increased rates of spending time in NOE (IRR= 1.48, 95% CI 1.45, 1.51) compared with non-dog owners. There were no differences in perceived general health status and mental health between dog owners and non-dog owners. City-specific analyses showed similar results, with some exceptions: a positive association between dog ownership and perceived general health in Barcelona (OR=1.90, 95% CI 1.01, 3.56); and a positive association between dog ownership and mental health in Stoke-on-Trent (β = 2.61, 95% CI 0.35, 4.86) (Table 2 and Supplemental Table S1).

(Table 2 here)

Stratified analyses by access to NOE and residential surrounding greenness

Stratified analyses showed that the association between dog ownership and leisure time walking for those with the highest number of NOE around their home (IRR= 1.72, 95% CI 1.71, 1.73) was stronger than for those with little NOE (IRR= 1.61, 95% CI 1.60, 1.62). Similar results were observed for those living within 300m of a NOE, and for those with a higher amount of residential surrounding greenness, but not

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3 consistently for larger areas of NOE. Stronger associations between dog ownership and walking were
4 predominantly observed for the access to NOE and surrounding greenness indicators in larger buffer sizes
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6 (Table 3 and Supplemental Table S2).
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10 The association between dog ownership and time spent in NOE by the number of NOE was also stronger
11 for those with a higher number of NOE (IRR 1.51, 95% CI 1.46, 1.56) compared to those with a lower
12 number of NOE (IRR 1.43, 95% CI 1.39, 1.47). We also observed stronger associations between dog
13 ownership and time spent in NOE for those with larger areas of NOE, for those living within 300m of a
14 NOE and for those with a higher amount of residential surrounding greenness (Table 3 and Supplemental
15 Table S2). The stronger associations between dog ownership and time spent in NOE for those with better
16 access to NOE and with more residential surrounding greenness were consistent across all buffer sizes
17 except for residential surrounding greenness within 100m (Supplemental Table S2).
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21 There were no associations between dog ownership and perceived general health status when stratifying
22 by access to NOE or residential surrounding greenness. Similarly, there was no indication for an
23 association between dog ownership and mental health in groups with high or low access to NOE and with
24 high or low residential surrounding greenness (Table 3).
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34 (Table 3 here)
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40 Sensitivity analysis

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42 Additional adjustments for smoking, BMI, frequency of contact with family and/or friends, and whether
43 respondents feel part of a group of friends, did not change the results (results available upon request).
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50 DISCUSSION

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52 Having a dog was associated with more leisure time walking and time spent in NOE near home compared
53 with not having a dog. Moreover, the differences in walking and time spent in NOE between dog owners
54 and non-dog owners were larger when there was good access to NOE and a high amount of residential
55 surrounding greenness. There was no consistent evidence for an association between dog ownership and
56 perceived general and mental health status. Only dog owners from Stoke-on-Trent had better mental
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3 health compared with non-dog owners, and dog owners from Barcelona had better perceived general
4 health compared to non-dog owners.
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8 Prior studies have also observed links between NOE, dog ownership and physical activity. In support of
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10 our findings, a UK study of older adults reported that neighborhood greenness was associated with a
11 smaller decline in physical activity over time, and that dog walking explained up to 50% of the variance
12 in the relationship between greenness and outdoor physical activity [61]. Our findings were also
13 consistent with a Danish study that found that dog ownership was a major determinant of park visits,
14 especially those parks closest to the residence [33]. Our study adds to the evidence base by including
15 multiple exposure indicators of NOE which enabled studying multiple exposure indicators of NOE
16 simultaneously, and could help understand what metric best predicts the health benefits associated with
17 NOE [34,35,39]. We found that dog owners spent more time in NOE than non-dog owners, but dog
18 ownership was not consistently related to perceived mental or general health status. Dog ownership was
19 only related to better perceived general or mental health in Barcelona and Stoke-on-Trent, the two cities
20 where respondents were the least active and spent the least time in NOE. This suggests that the health
21 benefits of dog ownership exist when walking and time spent in NOE is low to begin with. Because we
22 found no consistent evidence for health benefits for dog owners with better availability of NOE, future
23 studies could also investigate subjective indicators of NOE, including satisfaction and importance, and
24 neighborhood aesthetics [62].
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39 Although the cross-sectional nature of our study does not allow for understanding the longitudinal effects
40 of dog ownership on health, it is possible that people with physical constraints and chronic diseases more
41 often decide to have a dog, for example following doctor's advice, in order to stay mobile [24]. Similarly,
42 another study reported that dog owners more often had asthma, and a higher BMI compared with non-dog
43 owners [26]. Furthermore, an Australian study found that although pet ownership was associated with
44 higher levels of physical activity, it was also associated with higher self-reported BMI, higher diastolic
45 blood pressure, and smoking [25]. We found that despite the physical constraints and chronic diseases,
46 dog owners engaged in more leisure time walking than non-dog owners. We hypothesize that the extra
47 physical activity facilitated by dog walking may offset some of the other negative health risk factors dog
48 owners have, and could eventually yield longer term health benefits. This may especially occur in green
49 neighborhoods, when there is access to NOE and when the residential environment promotes walking.
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3 Limitations of this study include the lack of information about the dog (e.g. breed, age, temperament), the
4 dog owner's level of attachment to their dog, the duration of dog ownership, and if the respondent was the
5 primary carer of the dog. Such factors may have influenced the potential health benefits of dog
6 ownership, but we were unable to take these factors into account. We further did not know if the time
7 spent in NOE and leisure time walking was undertaken together with the dog, and whether time spent in
8 NOE was time spent walking. Future research should measure specific aspects of dog ownership and
9 should use measures of behavior such as time spent in NOE with and without dog and leisure time
10 walking undertaken with and without the dog. A limitation of self-reporting walking habits is potential
11 overstatement of the amount of walking. Although data collection was similar in each city, data on
12 neighborhood SES was based on country-specific data and this might have complicated comparisons
13 between cities. Finally, we cannot establish the direction of the observed relationships because of the
14 cross-sectional study design. For example, people who are already physically active and visit NOE may
15 decide to get a dog, instead of dogs motivating their owners to walk and visit NOE more. Strengths
16 include the multi-city approach, which revealed differences between cities concerning dog ownership and
17 health. It is also one of the first studies from mainland Europe, since the majority of research has been
18 carried out in North America, Australia, and in the UK. More international studies about dog ownership
19 and health are needed. Finally, our measure of access to NOE was specific to environments that were
20 suitable for physical activity. Also, for access to NOE, we used road network buffers over circular buffers
21 which better capture people's walking behavior; and we used varying buffer sizes to obtain a better
22 understanding of what distance to NOE is most beneficial to health [42].
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41 42 Conclusions

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45 Dog owners performed more leisure time walking and spent more time in NOE compared with non-dog
46 owners, especially when they had access to NOE and when they lived in green areas. There was no
47 consistent relationship between dog ownership and better perceived general or mental health status. In a
48 largely physically inactive society where many people remain indoors, dog walking in parks or other
49 NOE may be an opportunity to engage people in walking behavior as a path towards better health. Cities
50 should therefore ensure that there is access to NOE for dog owners and provide green infrastructure in
51 order to promote dog walking. Future research should focus on natural experiments and evaluation of
52 intervention strategies to increase dog owners' access to NOE.
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For peer review only

Tables.

Table 1. Population characteristics by dog-ownership

	Total n=3586	Non-dog- owner n=2478	Dog owner n=1108	adjusted p-value*
Age, mean (SD)	51.4 (15.9)	51.3 (15.9)	51.7 (16.0)	>.05
Sex, n (females %)	1967 (54.9)	1314 (53.0)	653 (58.9)	<.05
Household composition, n (%)				<.05
<i>alone</i>	614 (17.1)	461 (18.6)	153 (13.8)	
<i>with partner (without children)</i>	1239 (34.5)	864 (34.9)	375 (33.8)	
<i>with children <12 yr old</i>	535 (14.9)	383 (15.5)	152 (13.7)	
<i>with children >12 yr old</i>	602 (16.8)	368 (14.9)	234 (21.1)	
<i>other</i>	597 (16.6)	402 (16.2)	195 (17.6)	
City, n (%)				<.05
<i>Barcelona</i>	979 (27.3)	790 (31.9)	189 (17.1)	
<i>Doetinchem</i>	851 (23.7)	668 (27.0)	183 (16.5)	
<i>Kaunas</i>	892 (24.9)	436 (17.6)	456 (41.1)	
<i>Stoke-on-Trent</i>	864 (24.1)	584 (23.6)	280 (25.3)	
Education, n (%)				>.05
<i>low</i>	251 (7.0)	163 (6.6)	88 (7.9)	
<i>medium</i>	1568 (43.7)	1087 (43.9)	481 (43.5)	
<i>high</i>	1767 (49.3)	1228 (49.6)	539 (48.6)	
Perceived income situation, n (%)				<.05
<i>cannot make ends meet</i>	385 (10.7)	276 (11.1)	109 (9.8)	
<i>enough to get by</i>	1800 (50.2)	1165 (47.0)	635 (57.3)	
<i>comfortable</i>	1401 (39.1)	1037 (41.9)	364 (32.9)	
Weight status (BMI categories), n (%)				<.05
<i>healthy weight</i>	1610 (44.9)	1165 (47.0)	445 (40.2)	
<i>overweight</i>	1192 (33.2)	819 (33.1)	373 (33.6)	
<i>obese</i>	784 (21.9)	494 (19.9)	290 (26.2)	
Physical constraint restricting mobility, n (%)	1003 (25.4)	536 (19.9)	467 (37.3)	<.05
One or more chronic diseases, n (%)	1313 (36.6)	860 (34.7)	453 (40.9)	<.05
Minutes/week walking (leisure), median (IQR)	120 (300)	90 (240)	180 (420)	<.05
Smoking, n (%)				<.05
<i>current</i>	733 (20.5)	478 (19.3)	255 (23.0)	
<i>former</i>	1008 (28.1)	724 (29.2)	284 (25.6)	
<i>never</i>	1843 (51.4)	1275 (51.5)	568 (51.3)	
Frequency of contact with family and/or friends, n (%)				>.05
<i>(almost) daily</i>	2135 (59.5)	1470 (59.3)	665 (60.0)	
<i>≥1 per week</i>	1114 (31.1)	781 (31.1)	333 (30.0)	
<i>1-3 per month or less</i>	392 (9.4)	227 (9.2)	111 (10.0)	
Feeling part of a group of friends, n %				<.05
<i>(totally) agree</i>	2414 (67.5)	1754 (70.9)	660 (59.7)	
<i>neutral, (totally) disagree</i>	1165 (32.5)	719 (29.1)	446 (40.3)	
Perceived safety of NOE in NBH, n (%)				<.05
<i>(very) satisfied</i>	2123 (59.2)	1486 (60.0)	637 (57.5)	
<i>neutral</i>	776 (21.6)	542 (21.9)	234 (21.1)	
<i>(very) dissatisfied</i>	687 (19.2)	450 (18.2)	237 (21.4)	
NBH SES, n (%)				>.05
<i>low</i>	1131 (31.5)	791 (31.9)	340 (30.7)	

<i>medium</i>	1379 (38.4)	938 (37.9)	441 (39.8)	
<i>high</i>	1076 (30.0)	749 (30.2)	327 (29.5)	
Minutes/week walking (leisure), median (IQR)	120 (300)	90 (240)	180 (420)	<.05
Hours spent in NOE near home in last 4 wks, median (IQR)	4 (11.8)	3.75 (10)	10 (29.3)	<.05
General health, n (%)				<.05
<i>Excellent</i> , (very) good	2662 (74.2)	1939 (78.3)	723 (65.2)	
<i>(Very) Bad</i>	924 (25.8)	539 (21.8)	385 (34.8)	
Mental health (SF-36), mean (SD)	73.5 (16.3)	73.9 (16.2)	72.5 (16.3)	<.05
Distance to nearest NOE (m), median (IQR)	161.0 (214)	155.7 (205.6)	172.4 (232.4)	<.05
Number of NOE in 300m NWB, median (IQR)	1 (1)	1 (2)	1 (2)	<.05
Number of NOE in 500m NWB, median (IQR)	1 (1)	3 (3)	3 (3)	<.05
Number of NOE in 1000m NWB, median (IQR)	10 (10)	11 (10)	8 (10)	<.05
Area of NOE in 300m NWB (m ²), median (IQR)	38,013 (136,092)	36,007 (132,239)	41,241 (154,377)	>.05
Area of NOE in 500m NWB (m ²), median (IQR)	140,281 (286,917)	137,862 (261,453)	150,758 (402,966)	<.05
Area of NOE in 1000m NWB (m ²), median (IQR)	588,516 (975,551)	557,191 (890,303)	720,366 (239,293)	<.05
Distance to nearest NOE (m), median (IQR)	161.0 (214)	155.7 (205.6)	172.4 (232.4)	<.05
Average residential surrounding greenness in 100m buffer, median (IQR)	0.46 (0.16)	0.44 (0.28)	0.50 (0.16)	<.05
Average residential surrounding greenness in 300m buffer, median (IQR)	0.49 (0.23)	0.47 (0.30)	0.51 (0.13)	<.05
Average residential surrounding greenness in 500m buffer, median (IQR)	0.49 (0.23)	0.48 (0.31)	0.51 (0.11)	<.05

NOE= natural outdoor environments; NBH= neighborhood; NWB= network buffer; IQR= interquartile range; SD= standard deviation; BMI= body mass index; SES= socioeconomic status. * based on t-tests, Chi-square, Kruskal-Wallis, and rank-sum tests and with p-values adjusted for the false discovery rate with the Benjamini-Hochberg Procedure.

Table 2. Associations between dog-ownership, leisure time walking, time spent in NOE near the home, general health status and mental health.

	Leisure time walking (min/wk)	Time spent in NOE near home (h/wk)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
Dog ownership (vs. not)	IRR (95% CI)	IRR (95% CI)	OR (95% CI)	β (95% CI)
Total	1.65 (1.65; 1.66) n=3586	1.48 (1.45; 1.51) n=3530	0.92 (0.73; 1.15) n=3586	0.24 (-0.89; 1.37) n=3584
Barcelona	1.07 (1.06; 1.08) n=979	1.70 (1.62; 1.78) n=978	1.90 (1.01; 3.56) n=979	0.13 (-2.29; 2.55) n=979
Doetinchem	3.67 (3.63; 3.70) n=851	1.38 (1.32; 1.45) n=846	0.89 (0.37; 2.17) n=851	1.61 (-0.55; 3.78) n=849
Kaunas	1.10 (1.09; 1.11) n=892	1.19 (1.16; 1.23) n=844	0.71 (0.50; 1.00) n=892	-2.17 (-4.40; 0.06) n=892
Stoke-on-Trent	1.83 (1.81; 1.85) n=864	2.20 (2.11; 2.29) n=862	0.89 (0.57; 1.37) n=864	2.61 (0.35; 4.86) n=864

NOE= natural outdoor environments; IRR= incidence rate ratio; OR= odds ratio; CI= confidence interval

Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

Table 3. Associations between dog-ownership, walking, time in NOE, perceived general and mental health status by access to NOE and residential surrounding greenness.

		Leisure time walking (min/wk)	Time spent in NOE near home (h/wk)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
Dog ownership (vs. not)		IRR (95% CI)	IRR (95% CI)	OR (95% CI)	β (95% CI)
Number of NOE (500m)	lowest	1.61 (1.60; 1.62) n=2084	1.43 (1.39; 1.47) n=2051	0.89 (0.65; 1.22) n=2084	0.55 (-0.93; 2.03) n=2082
	highest	1.72 (1.71; 1.73) n=1502	1.51 (1.46; 1.56) n=1479	0.90 (0.62; 1.29) n=1502	-0.62 (-2.36; 1.13) n=1502
Area of NOE (500m)	lowest	1.76 (1.75; 1.77) n=1779	1.35 (1.30; 1.39) n=1753	0.90 (0.64; 1.27) n=1779	0.85 (-0.83; 2.53) n=1777
	highest	1.61 (1.60; 1.62) n=1807	1.60 (1.56; 1.65) n=1777	0.81 (0.59; 1.12) n=1807	-0.48 (-1.20; 1.04) n=1807
Distance to nearest NOE	≤300m	1.73 (1.72; 1.74) n=2778	1.52 (1.49; 1.56) n=2746	0.91 (0.69; 1.20) n=2778	0.66 (-0.61; 1.93) n=2776
	>300m	1.46 (1.44; 1.47) n=808	1.21 (1.16; 1.27) n=784	0.70 (0.46; 1.05) n=808	-1.05 (-3.45; 1.36) n=808
Residential surrounding greenness (500m)	lowest	1.55 (1.54; 1.56) n=1786	1.37 (1.33; 1.42) n=1765	0.86 (0.61; 1.21) n=1786	0.38 (-1.29; 2.05) n=1785
	highest	1.76 (1.74; 1.77) n=1800	1.61 (1.56; 1.65) n=1765	0.95 (0.68; 1.33) n=1800	-0.16 (-1.69; 1.36) n=1799

NOE= natural outdoor environments; IRR= incidence rate ratio; OR= odds ratio; CI= confidence interval. Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

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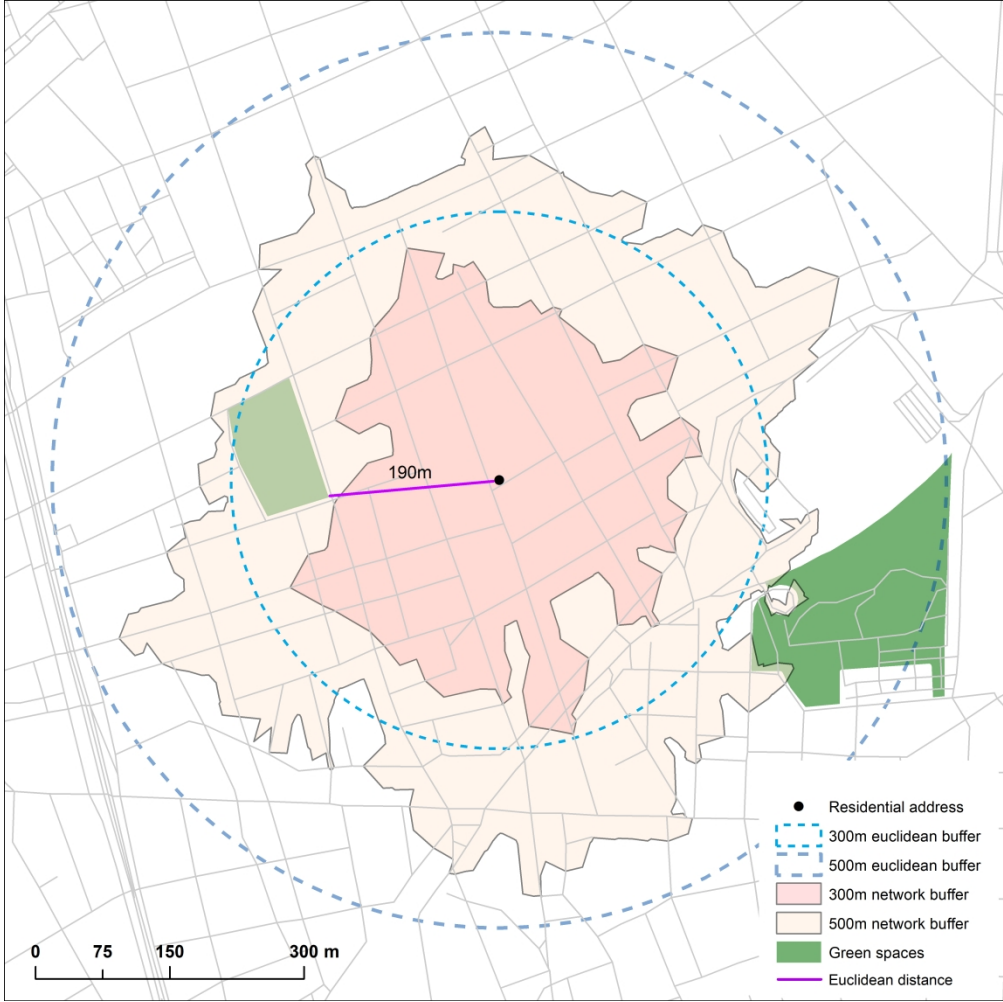


Figure 1. Example of different buffer types and the distance to natural outdoor environments from a residential address.

Supplemental Material Zijlema et al - Dog ownership, the natural outdoor environment and health: a cross-sectional study

Supplemental Table S1. Full model results of associations between dog-ownership, leisure time walking, time spent in NOE near the home, general health status and mental health.

	Leisure time walking (min/wk)	Time spent in NOE near home (h/wk)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
	IRR (95% CI)	IRR (95% CI)	OR (95% CI)	β (95% CI)
Dog ownership (vs. not)	1.65 (1.65; 1.66)	1.48 (1.45; 1.51)	0.92 (0.73; 1.15)	0.24 (-0.89; 1.37)
Female sex	1.09 (1.08; 1.09)	0.89 (1.45; 1.51)	1.12 (0.91; 1.38)	-2.07 (-3.08; -1.07)
Age	1.00 (1.00; 1.00)	1.01 (1.01; 1.01)	0.97 (0.96; 0.98)	0.07 (0.03; 0.11)
Household composition (vs. alone)				
<i>with partner (without children)</i>	0.97 (0.96; 0.97)	1.10 (1.07; 1.13)	1.01 (0.75; 1.37)	1.36 (-0.13; 2.85)
<i>with children <12 yr old</i>	0.90 (0.89; 0.91)	1.29 (1.24; 1.33)	0.88 (0.57; 1.36)	2.86 (0.95; 4.76)
<i>with children >12 yr old</i>	0.94 (0.93; 0.94)	1.17 (1.13; 1.21)	1.00 (0.70; 1.45)	1.77 (0.05; 3.49)
<i>other</i>	0.93 (0.92; 0.94)	1.02 (0.98; 1.06)	0.57 (0.39; 0.85)	1.16 (-0.75; 3.07)
Education (vs. low)				
<i>medium</i>	0.96 (0.81; 1.13)	1.33 (1.27; 1.40)	0.99 (0.65; 1.49)	3.70 (1.55; 5.84)
<i>high</i>	1.04 (0.88; 1.23)	1.56 (1.48; 1.63)	1.26 (0.81; 1.97)	4.91 (2.69; 7.12)
Perceived income situation (vs. cannot make ends meet)				
<i>enough to get by</i>	0.99 (0.98; 1.00)	0.98 (0.94; 1.01)	1.67 (1.19; 2.35)	2.92 (1.22; 4.63)
<i>comfortable</i>	1.05 (1.05; 1.06)	1.00 (0.96; 1.03)	5.00 (3.40; 7.36)	8.06 (6.26; 9.86)
Physical constraint restricting mobility (vs. not)	0.99 (0.99; 1.00)	0.89 (0.87; 0.91)	0.48 (0.39; 0.61)	-0.86 (-2.14; 0.41)
One or more chronic diseases (vs. not)	1.03 (1.03; 1.04)	1.02 (1.00; 1.04)	0.18 (0.14; 0.22)	-4.16 (-5.34; -2.98)
Perceived safety of NOE in NBH (vs. very satisfied)				
<i>satisfied</i>	1.05 (1.04; 1.06)	0.90 (0.87; 0.93)	1.01 (0.66; 1.56)	-2.47 (-4.33; -0.61)
<i>neutral</i>	0.96 (0.95; 0.97)	0.85 (0.81; 0.88)	0.72 (0.46; 1.15)	-4.65 (-6.70; -2.61)
<i>dissatisfied</i>	1.09 (1.08; 1.10)	0.85 (0.82; 0.89)	0.61 (0.38; 0.97)	-5.45 (-7.62; -3.28)
<i>very dissatisfied</i>	1.15 (1.14; 1.17)	1.37 (1.30; 1.45)	0.70 (0.36; 1.37)	-6.01 (-9.28; -2.73)
NBH SES (vs. low)				
<i>medium</i>	0.96 (0.81; 1.13)	1.02 (0.79; 1.30)	0.92 (0.45; 1.88)	-0.49 (-2.63; 1.64)
<i>high</i>	1.04 (0.88; 1.23)	0.96 (0.75; 1.23)	0.96 (0.46; 1.99)	0.89 (-1.33; 3.10)

NOE= natural outdoor environments; IRR= incidence rate ratio; OR= odds ratio; CI= confidence interval; NBH= neighborhood; SES= socioeconomic status. Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

Supplemental Material Zijlema et al - Dog ownership, the natural outdoor environment and health: a cross-sectional study

Supplemental Table S2. Associations between dog-ownership, walking, time in NOE, perceived general and mental health status by access to NOE and residential surrounding greenness

Dog ownership (vs. not)	Leisure time walking (min/wk)	Time spent in NOE near home (h/wk)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)	
	IRR (95% CI)	IRR (95% CI)	OR (95% CI)	β (95% CI)	
Number of NOE	300m				
	lowest	1.67 (1.66; 1.68) n=2414	1.41 (1.37; 1.44) n=2368	0.87 (0.66; 1.15) n=2414	0.37 (-0.99; 1.73) n=2412
	highest	1.62 (1.60; 1.63) n=1172	1.63 (1.57; 1.69) n=1162	0.84 (0.54; 1.29) n=1172	0.38 (-1.62; 2.39) n=1172
	1000m				
	lowest	1.56 (1.55; 1.57) n=1869	1.38 (1.34; 1.42) n=1843	0.85 (0.61; 1.18) n=1869	-0.72 (-2.24; 0.81) n=1867
	highest	1.75 (1.73; 1.76) n=1717	1.68 (1.63; 1.73) n=1687	0.87 (0.63; 1.22) n=1717	0.68 (-0.98; 2.34) n=1717
Area of NOE	300m				
	lowest	1.76 (1.75; 1.78) n=1832	1.37 (1.33; 1.41) n=1801	0.78 (0.56; 1.08) n=1832	-0.30 (-1.90; 1.30) n=1830
	highest	1.53 (1.52; 1.54) n=1754	1.53 (1.49; 1.58) n=1729	0.92 (0.65; 1.28) n=1754	0.61 (-0.97; 2.20) n=1754
	1000m				
	lowest	1.54 (1.53; 1.55) n=1799	1.26 (1.22; 1.30) n=1777	0.74 (0.53; 1.03) n=1799	-0.80 (-2.46; 0.87) n=1797
	highest	1.72 (1.70; 1.73) n=1787	1.66 (1.62; 1.71) n=1753	0.94 (0.67; 1.30) n=1787	0.65 (-0.88; 2.18) n=1787
Surrounding greenness (NDVI)	100m				
	lowest	1.54 (1.53; 1.55) n=1797	1.48 (1.43; 1.53) n=1769	0.74 (0.53; 1.03) n=1797	0.23 (-1.42; 1.89) n=1796
	highest	1.83 (1.81; 1.84) n=1789	1.46 (1.42; 1.50) n=1761	0.95 (0.68; 1.33) n=1789	-0.06 (-1.59; 1.47) n=1788
	300m				
	lowest	1.55 (1.53; 1.56) n=1786	1.48 (1.43; 1.53) n=1757	0.77 (0.54; 1.09) n=1786	0.43 (-1.25; 2.10) n=1785
	highest	1.81 (1.80; 1.82) n=1800	1.56 (1.51; 1.60) n=1773	0.98 (0.71; 1.36) n=1800	-0.11 (-1.62; 1.41) n=1799

NOE= natural outdoor environments; IRR= incidence rate ratio; OR= odds ratio; CI= confidence interval; NDVI= normalized difference vegetation index. Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

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

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

		cases and controls was addressed	
		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	
		(e) Describe any sensitivity analyses	10-11
Results			Appears in manuscript on page
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	-
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	-
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	n.a.
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	n.a.
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	n.a.
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	Table 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Tables, 11-12
		(b) Report category boundaries when continuous variables were categorized	Tables, 7-10
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n.a.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Tables, 12-13
Discussion			
Key results	18	Summarise key results with reference to study objectives	13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	13-14
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	4-5

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3 *Give information separately for cases and controls in case-control studies and, if applicable, for exposed and
4 unexposed groups in cohort and cross-sectional studies.
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6 **Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and
7 published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely
8 available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at
9 <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is
10 available at www.strobe-statement.org.
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BMJ Open

Dog ownership, the natural outdoor environment and health: a cross-sectional study

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5 Dog ownership, the natural outdoor environment and health: a cross-sectional study
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Abstract

Objectives

Dog owners walking their dog in natural outdoor environments (NOE) may benefit from the physical activity facilitated by dog walking and from time spent in nature. However, it is unclear whether dog owners receive additional health benefits associated with having access to NOE above the physical activity benefit of walking with their dog. We investigated associations between dog ownership, walking, time spent in NOE, and health and whether these associations differed among those with good and poor access to NOE and those living in green and less green areas.

Design

Cross-sectional study

Setting

The Positive Health Effects of the Natural Outdoor Environment in Typical Populations in Different Regions in Europe (PHENOTYPE) project.

Participants

n=3586 adults from Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania), and Stoke-on-Trent (United Kingdom).

Data collection and analysis

We calculated access to NOE with land maps and residential surrounding greenness with satellite data. Leisure time walking, time spent in NOE, and general and mental health status were measured using validated questionnaires. Associations were estimated using multilevel analysis with a random intercept defined at the neighborhood level.

Results

Dog ownership was associated with higher rates of leisure time walking and time spending in NOE (odds ratio 2.17, 95% CI 1.86, 2.54 and 2.37, 95% CI 2.02, 2.79 respectively). These associations were stronger

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3 in those living within 300m of a NOE and in greener areas. No consistent associations were found
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5 between dog ownership and perceived general or mental health status.
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7 8 Conclusions

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10 Compared with non-dog owners, dog owners walked more and spent more time in NOE, especially those
11
12 living within 300m of a NOE and in greener areas. The health implications of these relationships should
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14 be further investigated. In a largely physically inactive society, dog walking in NOE may be a simple way
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16 of promoting physical activity and health.
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22 • This is one of the first studies from mainland Europe, and the multi-city approach revealed
23
24 differences between cities concerning dog ownership and health.
- 25
26 • The assessment of access to natural outdoor environments suitable for physical activity using
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28 road network buffers was chosen to optimally capture the relation with people's walking
29
30 behavior.
- 31
32 • The use of multiple exposure indicators of natural outdoor environments enabled studying these
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34 exposure indicators simultaneously, and could help understand what metric best predicts the
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36 health benefits associated with natural outdoor environments.
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38 • We cannot establish the direction of the observed relationships because of the cross-sectional
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40 study design.
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44 • We had no detailed information about dog ownership (e.g. level of attachment, duration of dog
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46 ownership, primary caretaker) and we did not know if the time spent in natural outdoor
47
48 environments and leisure time walking was undertaken together with the dog.
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54 55 Competing interests

56
57
58 None declared
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Author's Contributions

WLZ conducted the analyses. WLZ, HC and JL drafted the manuscript. MTM, MC, MB, JM, CG, HK, WWV, SA, RG, MJN were involved in the design of and data acquisition in the PHENOTYPE study. All authors provided input on the manuscript and agreed with the final version.

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Data sharing statement

Additional data are available upon request from the corresponding author (WLZ:

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INTRODUCTION

In an urbanized world, where people spend the majority of their time indoors [1], physical inactivity is a major public health problem [2]. It not only leads to adverse health effects but it is also a large economic burden for society [3]. Physical activity behavior is influenced by many factors. Apart from individual-level factors including age, sex, and health status, the built environment is an important determinant of physical activity [4,5]. Aspects of the built environment such as the availability of parks are associated with increased physical activity, especially walking [6,7]. It is important to identify sustainable built environment interventions for increasing physical activity and improving health.

Promotion of walking could be a population-level strategy to address physical inactivity. As such, and considering the prevalence of dog ownership (e.g. 18% in the Netherlands [8]), dog walking has been identified as a simple way of promoting physical activity [9–12]. There is strong evidence to suggest that dog owners walk more often and are more physically active than non-dog owners [12–14]. This association has been observed in adults [15,16], adolescents and children [17–19], in groups with potential limited mobility such as older adults [20–22] and in people with a chronic disease [23]. Consequently, dog walking may lead to better health over time, with benefits ranging from improved wellbeing [24] to fewer doctor visits [25] and a lower risk of cardiovascular disease and mortality [26].

However, not all studies show health benefits of dog ownership [27–29] and a large proportion of dog owners do not walk their dog [30,31]. Of the various factors that influence dog walking behavior, aspects of the built environment seem to be among them [11]. Supportive environments, such as neighborhoods with parks and other types of green infrastructure, are associated with higher physical activity levels of dog owners and are important for promoting dog walking [10,11,32]. Specifically, better park access and park quality (e.g. presence of dog litter bags, water sources) were related to dog walking [11,33,34]. Not all dog owners have access to parks thus improving access to parks in residential areas could be important for facilitating dog walking, especially since local parks are a common place for dog walking [35]. Parks also provide an opportunity for nature contact. Spending time in natural outdoor environments (NOE), such as parks, has been associated with health benefits, for example through facilitating stress reduction, restoration, and social contact [36–38]. Dog owners walking their dog in NOE may benefit from the physical activity facilitated by owning a dog as well as time spent in nature. However, it is unclear whether dog owners receive additional health benefits associated with having access to NOE. According to the theories of health behavior [39] and the social ecological framework [40], identifying the environmental

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3 factors that influence health outcomes (e.g. access to NOE) could lead to potential intervention strategies
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5 that could eventually improve health.
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8 The aim of this study was to investigate the relationships between dog ownership, walking, the NOE and
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10 health. In line with above-mentioned studies and health behavior theories, we hypothesized that dog owners
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12 walk more, spend more time in NOE and are healthier than non-dog owners, and that the health benefits
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14 are more apparent in dog owners within green neighborhoods and with access to NOE compared to those
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16 in less green areas and with poor NOE access. We therefore investigated the associations between dog
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18 ownership, leisure time walking, time spent in NOE, and general and mental health status, and whether
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20 these associations differed among those with good and poor access to NOE and those living in green and
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22 less green areas.
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24 METHOD

25 26 Study design and participants 27

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29 This study analyzed data from the Positive Health Effects of the Natural Outdoor environment in Typical
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31 Populations in different regions in Europe (PHENOTYPE) project. Respondents were recruited from 30
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33 different neighborhoods in Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania), and
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35 Stoke-on-Trent (United Kingdom) [41,42]. Neighborhoods were selected to maximize variability in access
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37 to NOE and socioeconomic status. In order to arrive at a final sample of approximately 1000 respondents
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39 per city, a random sample of 30 to 35 addresses per neighborhood were mailed with a letter explaining the
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41 purpose of the project after which they were visited by interviewers. In Doetinchem, persons were asked to
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43 send back an answer card to indicate their willingness to participate before they were visited by the
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45 interviewers; and in Kaunas, persons were approached by mail to fill out postal questionnaires. Respondents
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47 needed to have an age between 18 and 75 years and to be able to speak the local language. Data were
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49 collected using interview-administered questionnaires (except in Kaunas, where self-administered
50
51 questionnaires were used) at respondents' residences during May-November 2013. The study was
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53 conducted in accordance with the Declaration of Helsinki. All respondents provided written informed
54
55 consent and study protocols were approved by local ethical committees (Parc de Salut Mar, Clinical
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57 Research Ethics Committee reference number 2011/4206/I; Medisch Ethische Toestingscommissie UMCU
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59 reference number 12/595; Lietuvos Bioetikos Komitetas reference number 6B-12-147; Faculty of Health
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61 Sciences' Ethics Panel, no reference number).

Patient and Public Involvement

Participant and stakeholder involvement and dissemination of results was organized in multiple ways through symposia, workshops, online media channels and newsletters. Members of the public were not directly involved in the design or conception of the study.

Data

Explanatory variables

Dog ownership

Dog ownership was assessed using the question: “Do you own a dog” (yes; no).

Access to NOE was estimated with land use maps from local sources in each city (details in [42]). Only NOE that were publically available; suitable for physical activity; and at least 0.5 hectare (e.g. parks, semi-natural/natural land, formal recreation grounds) or 0.25 hectare (natural/green corridors) were selected as these were relevant for physical activity [42] and therefore potentially relevant in terms of the health benefits of NOE for dog owners. Road network buffers were chosen over circular buffers in order to capture a more realistic measure of NOE accessibility on foot [43], which may be most relevant to dog walking. We furthermore used three predetermined buffer sizes to obtain a better understanding of what distance to NOE is most beneficial to health [44]. Using GIS we constructed three indicators: (1) the number of, and (2) the total surface area NOE within road network buffers of 300m, 500m, and 1000m, and (3) the road network distance to the nearest NOE (Figure 1). The number of and area of NOE were dichotomized using the city-specific median values. Distance to nearest NOE was dichotomized using a 300m cut off according to guidelines [45].

Residential surrounding greenness was assessed using the normalized difference vegetation index (NDVI). The NDVI is a measure of vegetation and represents the photosynthetic activity in an area [42,46]. Healthy vegetation absorbs most visible light and reflects large parts of near-infrared light, while sparse vegetation reflects more visible light and less near-infrared light. Based on this distinction a value between -1 and +1 is calculated, with higher values indicating a higher density of green vegetation [46]. The NDVI was derived from Landsat 5 and 8 satellite images at a resolution of 30 m × 30 m on cloud-free images within the greenest season (April to September) in the relevant period for this study (2011-2013). Average NDVI

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3 values were calculated within (Euclidean) buffers of 100m, 300m, and 500m around the residence, as used
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5 in previous research [47,48], and dichotomized using the city-specific median value.
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8
9 (Figure 1 here)

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11 Figure 1. Example of different buffer types and the distance to natural outdoor environments from a
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13 residential address.
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16 Outcome variables

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19 Leisure time walking

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21 Walking in leisure time was assessed by the following questions: “When thinking about a normal week in
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23 the past month how many days per week do you walk in your leisure time” and “How much time (minutes)
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25 per day do you spend walking in your leisure time”. These items were derived from the short questionnaire
26
27 to assess health-enhancing physical activity (SQUASH) [49]. The SQUASH is a valid measure of physical
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29 activity [49,50]. Duration and frequency of walking was multiplied to create a composite variable of
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31 minutes per week of leisure time walking. This composite variable was then dichotomized using the median
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33 (120 minutes/week) as a cut point. City-specific cut points were made for city-specific analyses (Barcelona:
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35 120 min/week; Doetinchem: 120 min/week; Kaunas: 240 min/week; and Stoke-on-Trent: 20 min/week).
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38 Time spent in NOE

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40 NOE were defined as all public and private outdoor spaces that contain ‘green’ and/or ‘blue’ natural
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42 elements such as street trees, forests, city parks and natural parks/reserves, and also included all types of
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44 waterbodies such as canals, ponds, creeks, rivers, beaches. Time spent in NOE was assessed using two
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46 questions: “How often did you visit/go in the last 4 weeks on purpose to green or blue space near your
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48 home?” (5-point response scale ranging from ‘never’ (1) to ‘almost daily’ (5)); and “How much time did
49
50 you spend in a green or blue space near your home?” (4-point response scale ranging from <1 h (1) to 6–
51
52 10 h (4)). A composite variable was created to determine the amount of time (frequency of visits multiplied
53
54 by average duration per visit) respondents spent in NOE near home per month. As frequency and duration
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56 were assessed with questions with categorical response scales, the central value of each answer category
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58 for frequency were multiplied with central value of each answer category for duration (e.g. 3-5 h/month
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60 was coded as 4 h/month). The composite variable was then dichotomized using the median (4 hours/month)

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3 as a cut point. City-specific cut points were made for city-specific analyses (Barcelona: 3.75 h/month;
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5 Doetinchem: 10 h/month; Kaunas: 4 h/month; and Stoke-on-Trent: 1 h/month).

6 7 8 General health status

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10 General health status was assessed using the question: “In general what would you say your health is?” (5
11
12 point response scale: excellent to poor), which was derived from the Medical Outcome Study Short Form
13
14 (SF-36) [51]. Scores were dichotomized into “fair or poor” (0) and “excellent, very good, and good” (1).
15
16 This single question has been found to be associated with poor health outcomes in the general population
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18 [52,53].

19 20 21 Mental health

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23 Mental health was assessed using the Short Form Health Survey (SF-36) mental health subscale, including
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25 five items (e.g. nervousness, depression), and is a valid and reliable measure of mental health [54].
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27 Respondents rated the occurrence of symptoms in the past four weeks on a 6-point scale ranging from “all
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29 of the time” (1) to “none of the time” (6). A sum score was calculated and transformed into a scale ranging
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31 from 0 to 100 according to guidelines [51] with higher scores indicating better mental health. When ≥ 3
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33 items were missing, respondents were excluded from the analyses, but when 1-2 items were missing,
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35 missing values were replaced by the average score of the other items. We did this for 17 respondents.
36
37 Analyses including and excluding these 17 respondents did not alter the results.

38 39 40 Covariates and other variables

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42 Information about sociodemographic factors included sex, age, educational level (primary school or no
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44 education; secondary school/ further education (up to 18 years); university degree or higher), household
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46 composition (alone; with partner (without children); with children <12 yr old; with children >12 yr old; and
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48 other), perceived income situation (cannot make ends meet; enough to get by; comfortable), frequency of
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50 contact with family and/or friends ((almost daily; ≥ 1 per week; 1-3 per month or less), and whether
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52 respondents feel part of a group of friends ((totally) agree; neutral, (totally) disagree). We also included
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54 perceived safety of neighborhood NOE (very satisfied; satisfied; neutral; dissatisfied; very dissatisfied).
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56 Health-related factors included disability restricting mobility (yes; no), one or more chronic diseases (yes;
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58 no), body mass index (based on self reported height and weight: healthy weight ≤ 25 kg/m²; overweight 25-
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60 30 kg/m²; obese >30 kg/m²), and smoking status (current; former; never). Neighborhood socioeconomic

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3 status (SES, low; intermediate; high) was based on country-specific data (Barcelona: deprivation index
4 based on census data 2001 [55]; Doetinchem: average monthly household income per 6-digit zip code
5 level [56]; Kaunas: neighborhood education level [57]; Stoke-on-Trent: English indices of deprivation 2010
6 [58]).
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10 11 12 13 14 Statistical analyses 15

16
17 Equivalence tests with Benjamini-Hochberg adjustments for false discovery rates (5%) [59] were used to
18 test for differences between dog owner and non-dog owner characteristics. To investigate the association
19 between dog ownership, and outcomes leisure time walking, time spent in NOE, and general and mental
20 health status, and whether these associations differed for respondents with good/poor access to NOE and
21 high/low residential surrounding greenness, we investigated:
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27 1. The associations between dog ownership, and outcomes leisure time walking, time spent in NOE,
28 general health status, and mental health.
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- 30
31 2. The associations specified at 1, stratified by NOE access (good and poor) and by residential
32 surrounding greenness (high and low) to investigate whether the associations between dog
33 ownership and the outcomes differ in these subgroups.
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38 Associations were estimated using multilevel analysis with a random intercept defined at the neighborhood
39 level. Associations with leisure time walking, time spent in NOE and general health status were estimated
40 with logistic regression because of the dichotomization of the data; and since mental health scores were
41 normally distributed, associations were estimated with linear regression. Models were adjusted for age, sex,
42 education level, household composition, perceived income situation, neighborhood SES, NOE safety,
43 disability restricting mobility, and chronic diseases and were selected because of an assumed relation with
44 dog ownership, walking, time spent in NOE and health. The main associations (as specified at 1) were also
45 estimated for the cities separately. Stratified analyses by access to NOE and residential surrounding
46 greenness were undertaken with indicators in all buffer sizes, but the 500m buffer was reported in the main
47 table and the remaining buffer sizes in the Supplement. Analyses were based on complete cases (missing
48 data differed by outcome and ranged between n=360 and 416). All analyses were performed in STATA
49 14.2 [60].
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3 Sensitivity analyses were undertaken to investigate whether additional adjustment for covariates changed
4 the associations. Additional adjustments were carried out for characteristics that were found to differ
5 between dog owners and non-dog owners and that may relate to health (smoking and BMI), or that have
6 been found to be mediators of the dog ownership-health relationship (frequency of contact with family
7 and/or friends, and whether respondents feel part of a group of friends) [61,62].
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RESULTS

Population characteristics

Respondents were on average 51.4 (SD 15.9) years old and 54.9% were female. A total of 1109 (30.9%) respondents were dog owners. Dog owners compared with non-dog owners were on average the same age, had similar educational attainment but more were female (59.6% vs. 53.3%) and reported lower perceived income security. Dog ownership varied across cities, with it being highest in Kaunas (41.1%) and lowest in Doetinchem (16.5%). Dog owners walked more and spent more time in NOE compared with non-dog owners. However, dog owners had a lower perceived general and mental health status compared with non-dog owners. Dog owners also reported more frequently that physical constraints restricted their mobility, had more often a chronic disease, and had higher BMI than non-dog owners (Table 1).

(Table 1 here)

Dog ownership, leisure time walking, time spent in NOE and health

Adjusted multilevel models showed that dog ownership was associated with increased odds of walking ≥ 121 minutes per week (i.e. higher than the median amount of walking) (odds ratio [OR]= 2.17, 95% CI 1.86, 2.54) compared with non-dog owners. Dog ownership was also associated with increased odds of spending ≥ 4 hours/month in NOE (i.e. higher than the median amount of time in NOE) (OR= 2.37, 95% CI 2.02, 2.79) compared with non-dog owners. There were no differences in perceived general health status and mental health between dog owners and non-dog owners. City-specific analyses showed similar results, with some exceptions: a positive association between dog ownership and perceived general health in Barcelona (OR=1.90, 95% CI 1.01, 3.56); and a positive association between dog ownership and mental health in Stoke-on-Trent (β = 2.61, 95% CI 0.35, 4.86) (Table 2 and Supplemental Table S1).

(Table 2 here)

Stratified analyses by access to NOE and residential surrounding greenness

Generally, stratified analyses showed that the associations between dog ownership and leisure time walking by number and area of NOE were similar. The association between dog ownership and leisure time walking was stronger for those living within 300m of a NOE (OR= 2.36, 95% CI 1.97, 2.83) compared to those living within >300m of a NOE (OR= 1.86, 95% CI 1.36, 2.55; Table 3). Similar results were observed for

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3 those with a high amount of residential surrounding greenness (100 and 300m buffer, Supplemental Table
4 S2) compared to low residential surrounding greenness.
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8 The associations between dog ownership and time spent in NOE were larger for those with a lower number
9 or area of NOE than for those with a higher number or area of NOE (Table 3 and Supplemental Table S2).
10 We observed stronger associations between dog ownership and time spent in NOE for those living within
11 300m of a NOE (OR= 2.64, 95% CI 2.18, 3.20) compared to those living within >300m of a NOE (OR=
12 1.82, 95% CI 1.31, 2.55; Table 3). Stronger associations between dog ownership and time spent in NOE
13 for those with more residential surrounding greenness were consistent across buffer sizes 300m and 500m,
14 but not for residential surrounding greenness within 100m (Table 3 and Supplemental Table S2).
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22 There were no associations between dog ownership and perceived general health status when stratifying by
23 access to NOE or residential surrounding greenness. Similarly, there was no indication for an association
24 between dog ownership and mental health in groups with high or low access to NOE and with high or low
25 residential surrounding greenness (Table 3).
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30 (Table 3 here)
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36 Sensitivity analysis

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38 Additional adjustments for smoking, BMI, frequency of contact with family and/or friends, and whether
39 respondents feel part of a group of friends, did not change the results (results available upon request).
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46 DISCUSSION

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48 Having a dog was associated with more leisure time walking and time spent in NOE near home compared
49 with not having a dog. Moreover, the differences in walking and time spent in NOE between dog owners
50 and non-dog owners were larger when there was a NOE within 300m of the residence, and a high amount
51 of residential surrounding greenness. There was no consistent evidence for an association between dog
52 ownership and perceived general and mental health status. Only dog owners from Stoke-on-Trent had better
53 mental health compared with non-dog owners, and dog owners from Barcelona had better perceived general
54 health compared to non-dog owners.
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3 Prior studies have also observed links between NOE, dog ownership and physical activity. In support of
4 our findings, a UK study of older adults reported that neighborhood greenness was associated with a smaller
5 decline in physical activity over time, and that dog walking explained up to 50% of the variance in the
6 relationship between greenness and outdoor physical activity [63]. Our findings were also consistent with
7 a Danish study that found that dog ownership was a major determinant of park visits, especially those parks
8 closest to the residence [35]. Our study adds to the evidence base by including multiple exposure indicators
9 of NOE which enabled studying multiple exposure indicators of NOE simultaneously, and could help
10 understand what metric best predicts the health benefits associated with NOE [36,37,41]. We found that
11 dog owners spent more time in NOE than non-dog owners, but dog ownership was not consistently related
12 to perceived mental or general health status. Dog ownership was only related to better perceived general or
13 mental health in Barcelona and Stoke-on-Trent, the two cities where respondents were the least active and
14 spent the least time in NOE. This suggests that the health benefits of dog ownership exist when walking
15 and time spent in NOE is low to begin with. Because we found no consistent evidence for health benefits
16 for dog owners with better availability of NOE, future studies could also investigate subjective indicators
17 of NOE, including satisfaction and importance, and neighborhood aesthetics [64].

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20 Although the cross-sectional nature of our study does not allow for understanding the longitudinal effects
21 of dog ownership on health, it is possible that people with physical constraints and chronic diseases more
22 often decide to have a dog, for example following doctor's advice, in order to stay mobile [26]. Similarly,
23 another study reported that dog owners more often had asthma, and a higher BMI compared with non-dog
24 owners [28]. Furthermore, an Australian study found that although pet ownership was associated with
25 higher levels of physical activity, it was also associated with higher self-reported BMI, higher diastolic
26 blood pressure, and smoking [27]. We found that despite the physical constraints and chronic diseases, dog
27 owners engaged in more leisure time walking than non-dog owners. We hypothesize that the extra physical
28 activity facilitated by dog walking may offset some of the other negative health risk factors dog owners
29 have, and could eventually yield longer term health benefits. This may especially occur in green
30 neighborhoods, when there is access to NOE and when the residential environment promotes walking.

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33 Limitations of this study include the lack of information about the dog (e.g. breed, age, temperament), the
34 dog owner's level of attachment to their dog, the duration of dog ownership, and if the respondent was the
35 primary carer of the dog. Such factors may have influenced the potential health benefits of dog ownership,
36 but we were unable to take these factors into account. We further did not know if the time spent in NOE
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3 and leisure time walking was undertaken together with the dog, and whether time spent in NOE was time
4 spent walking. Future research should measure specific aspects of dog ownership and should use measures
5 of behavior such as time spent in NOE with and without dog and leisure time walking undertaken with and
6 without the dog. A limitation of self-reporting walking habits is potential overstatement of the amount of
7 walking. Minutes of walking and time in NOE were dichotomized because of non-normal distributions and
8 although this resulted in easier interpretation of data, it also resulted in information loss. Although data
9 collection was similar in each city, data on neighborhood SES was based on country-specific data and this
10 might have complicated comparisons between cities. Finally, we cannot establish the direction of the
11 observed relationships because of the cross-sectional study design. For example, people who are already
12 physically active and visit NOE may decide to get a dog, instead of dogs motivating their owners to walk
13 and visit NOE more. Strengths include the multi-city approach, which revealed differences between cities
14 concerning dog ownership and health. It is also one of the first studies from mainland Europe, since the
15 majority of research has been carried out in North America, Australia, and in the UK. More international
16 studies about dog ownership and health are needed. Finally, our measure of access to NOE was specific to
17 environments that were suitable for physical activity. Also, for access to NOE, we used road network
18 buffers over circular buffers which better capture people's walking behavior; and we used varying buffer
19 sizes to obtain a better understanding of what distance to NOE is most beneficial to health [44].
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36 Conclusions

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39 Dog owners performed more leisure time walking and spent more time in NOE compared with non-dog
40 owners, especially when they lived within 300m of a NOE and when they lived in green areas. There was
41 no consistent relationship between dog ownership and better perceived general or mental health status. In
42 a largely physically inactive society where many people remain indoors, dog walking in parks or other NOE
43 may be an opportunity to engage people in walking behavior as a path towards better health. Cities should
44 therefore ensure that there is access to NOE for dog owners and provide green infrastructure in order to
45 promote dog walking. Future research should focus on natural experiments and evaluation of intervention
46 strategies to increase dog owners' access to NOE.
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Tables.

Table 1. Population characteristics by dog-ownership

	Total n=3586	Non-dog- owner n=2478	Dog owner n=1108	adjusted p-value*
Age, mean (SD)	51.4 (15.9)	51.3 (15.9)	51.7 (16.0)	>.05
Sex, n (females %)	1967 (54.9)	1314 (53.0)	653 (58.9)	<.05
Household composition, n (%)				<.05
<i>alone</i>	614 (17.1)	461 (18.6)	153 (13.8)	
<i>with partner (without children)</i>	1239 (34.5)	864 (34.9)	375 (33.8)	
<i>with children <12 yr old</i>	535 (14.9)	383 (15.5)	152 (13.7)	
<i>with children >12 yr old</i>	602 (16.8)	368 (14.9)	234 (21.1)	
<i>other</i>	597 (16.6)	402 (16.2)	195 (17.6)	
City, n (%)				<.05
<i>Barcelona</i>	979 (27.3)	790 (31.9)	189 (17.1)	
<i>Doetinchem</i>	851 (23.7)	668 (27.0)	183 (16.5)	
<i>Kaunas</i>	892 (24.9)	436 (17.6)	456 (41.1)	
<i>Stoke-on-Trent</i>	864 (24.1)	584 (23.6)	280 (25.3)	
Education, n (%)				>.05
<i>low</i>	251 (7.0)	163 (6.6)	88 (7.9)	
<i>medium</i>	1568 (43.7)	1087 (43.9)	481 (43.5)	
<i>high</i>	1767 (49.3)	1228 (49.6)	539 (48.6)	
Perceived income situation, n (%)				<.05
<i>cannot make ends meet</i>	385 (10.7)	276 (11.1)	109 (9.8)	
<i>enough to get by</i>	1800 (50.2)	1165 (47.0)	635 (57.3)	
<i>comfortable</i>	1401 (39.1)	1037 (41.9)	364 (32.9)	
Weight status (BMI categories), n (%)				<.05
<i>healthy weight</i>	1610 (44.9)	1165 (47.0)	445 (40.2)	
<i>overweight</i>	1192 (33.2)	819 (33.1)	373 (33.6)	
<i>obese</i>	784 (21.9)	494 (19.9)	290 (26.2)	
Physical constraint restricting mobility, n (%)	1003 (25.4)	536 (19.9)	467 (37.3)	<.05
One or more chronic diseases, n (%)	1313 (36.6)	860 (34.7)	453 (40.9)	<.05
Minutes/week walking (leisure), median (IQR)	120 (300)	90 (240)	180 (420)	<.05
Smoking, n (%)				<.05
<i>current</i>	733 (20.5)	478 (19.3)	255 (23.0)	
<i>former</i>	1008 (28.1)	724 (29.2)	284 (25.6)	
<i>never</i>	1843 (51.4)	1275 (51.5)	568 (51.3)	
Frequency of contact with family and/or friends, n (%)				>.05
<i>(almost) daily</i>	2135 (59.5)	1470 (59.3)	665 (60.0)	
<i>≥1 per week</i>	1114 (31.1)	781 (31.1)	333 (30.0)	
<i>1-3 per month or less</i>	392 (9.4)	227 (9.2)	111 (10.0)	
Feeling part of a group of friends, n %				<.05
<i>(totally) agree</i>	2414 (67.5)	1754 (70.9)	660 (59.7)	
<i>neutral, (totally) disagree</i>	1165 (32.5)	719 (29.1)	446 (40.3)	
Perceived safety of NOE in NBH, n (%)				<.05
<i>(very) satisfied</i>	2123 (59.2)	1486 (60.0)	637 (57.5)	
<i>neutral</i>	776 (21.6)	542 (21.9)	234 (21.1)	
<i>(very) dissatisfied</i>	687 (19.2)	450 (18.2)	237 (21.4)	
NBH SES, n (%)				>.05
<i>low</i>	1131 (31.5)	791 (31.9)	340 (30.7)	

<i>medium</i>	1379 (38.4)	938 (37.9)	441 (39.8)	
<i>high</i>	1076 (30.0)	749 (30.2)	327 (29.5)	
Minutes/week walking (leisure), median (IQR)	120 (300)	90 (240)	180 (420)	<.05
Hours spent in NOE near home in last 4 wks, median (IQR)	4 (11.8)	3.75 (10)	10 (29.3)	<.05
General health, n (%)				<.05
<i>Excellent</i> , (very) good	2662 (74.2)	1939 (78.3)	723 (65.2)	
<i>(very) Bad</i>	924 (25.8)	539 (21.8)	385 (34.8)	
Mental health (SF-36), mean (SD)	73.5 (16.3)	73.9 (16.2)	72.5 (16.3)	<.05
Distance to nearest NOE (m), median (IQR)	161.0 (214)	155.7 (205.6)	172.4 (232.4)	<.05
Number of NOE in 300m NWB, median (IQR)	1 (1)	1 (2)	1 (2)	<.05
Number of NOE in 500m NWB, median (IQR)	1 (1)	3 (3)	3 (3)	<.05
Number of NOE in 1000m NWB, median (IQR)	10 (10)	11 (10)	8 (10)	<.05
Area of NOE in 300m NWB (m ²), median (IQR)	38,013 (136,092)	36,007 (132,239)	41,241 (154,377)	>.05
Area of NOE in 500m NWB (m ²), median (IQR)	140,281 (286,917)	137,862 (261,453)	150,758 (402,966)	<.05
Area of NOE in 1000m NWB (m ²), median (IQR)	588,516 (975,551)	557,191 (890,303)	720,366 (239,293)	<.05
Distance to nearest NOE (m), median (IQR)	161.0 (214)	155.7 (205.6)	172.4 (232.4)	<.05
Average residential surrounding greenness in 100m buffer, median (IQR)	0.46 (0.16)	0.44 (0.28)	0.50 (0.16)	<.05
Average residential surrounding greenness in 300m buffer, median (IQR)	0.49 (0.23)	0.47 (0.30)	0.51 (0.13)	<.05
Average residential surrounding greenness in 500m buffer, median (IQR)	0.49 (0.23)	0.48 (0.31)	0.51 (0.11)	<.05

NOE= natural outdoor environments; NBH= neighborhood; NWB= network buffer; IQR= interquartile range; SD= standard deviation; BMI= body mass index; SES= socioeconomic status. * based on t-tests, Chi-square, Kruskal-Wallis, and rank-sum tests and with p-values adjusted for the false discovery rate with the Benjamini-Hochberg Procedure.

Table 2. Associations between dog-ownership, leisure time walking, time spent in NOE near the home, general health status and mental health.

	Leisure time walking (high vs. low)	Time spent in NOE near home (high vs. low)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
Dog ownership (vs. not)	OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)
Total	2.17 (1.86; 2.54) n=3586	2.37 (2.02; 2.79) n=3530	0.92 (0.73; 1.15) n=3586	0.24 (-0.89; 1.37) n=3584
Barcelona	1.46 (1.03; 2.08) n=979	2.14 (1.47; 3.13) n=978	1.90 (1.01; 3.56) n=979	0.13 (-2.29; 2.55) n=979
Doetinchem	7.97 (5.18; 12.25) n=851	1.18 (0.80; 1.73) n=846	0.89 (0.37; 2.17) n=851	1.61 (-0.55; 3.78) n=849
Kaunas	1.05 (0.79; 1.39) n=892	1.26 (0.93; 1.69) n=844	0.71 (0.50; 1.00) n=892	-2.17 (-4.40; 0.06) n=892
Stoke-on-Trent	2.01 (1.44; 2.79) n=864	2.31 (1.63; 3.27) n=862	0.89 (0.57; 1.37) n=864	2.61 (0.35; 4.86) n=864

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval

Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

Table 3. Associations between dog-ownership, walking, time in NOE, perceived general and mental health status by access to NOE and residential surrounding greenness.

		Leisure time walking (high vs. low)	Time spent in NOE near home (high vs. low)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
Dog ownership (vs. not)		OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)
Number of NOE (500m)	lowest	2.13 (1.74; 2.62) n=2084	2.57 (2.07; 3.17) n=2051	0.89 (0.65; 1.22) n=2084	0.55 (-0.93; 2.03) n=2082
	highest	2.29 (1.79; 2.94) n=1502	2.23 (1.72; 2.89) n=1479	0.90 (0.62; 1.29) n=1502	-0.62 (-2.36; 1.13) n=1502
Area of NOE (500m)	lowest	2.36 (1.88; 2.97) n=1779	2.53 (2.00; 3.20) n=1753	0.90 (0.64; 1.27) n=1779	0.85 (-0.83; 2.53) n=1777
	highest	2.04 (1.64; 2.53) n=1807	2.19 (1.75; 2.75) n=1777	0.81 (0.59; 1.12) n=1807	-0.48 (-1.20; 1.04) n=1807
Distance to nearest NOE	≤ 300 m	2.36 (1.97; 2.83) n=2778	2.64 (2.18; 3.20) n=2746	0.91 (0.69; 1.20) n=2778	0.66 (-0.61; 1.93) n=2776
	> 300 m	1.86 (1.36; 2.55) n=808	1.82 (1.31; 2.55) n=784	0.70 (0.46; 1.05) n=808	-1.05 (-3.45; 1.36) n=808
Residential surrounding greenness (500m)	lowest	2.15 (1.70; 2.71) n=1786	2.29 (1.81; 2.91) n=1765	0.86 (0.61; 1.21) n=1786	0.38 (-1.29; 2.05) n=1785
	highest	2.19 (1.77; 2.72) n=1800	2.57 (2.04; 3.24) n=1765	0.95 (0.68; 1.33) n=1800	-0.16 (-1.69; 1.36) n=1799

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval. *Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.*

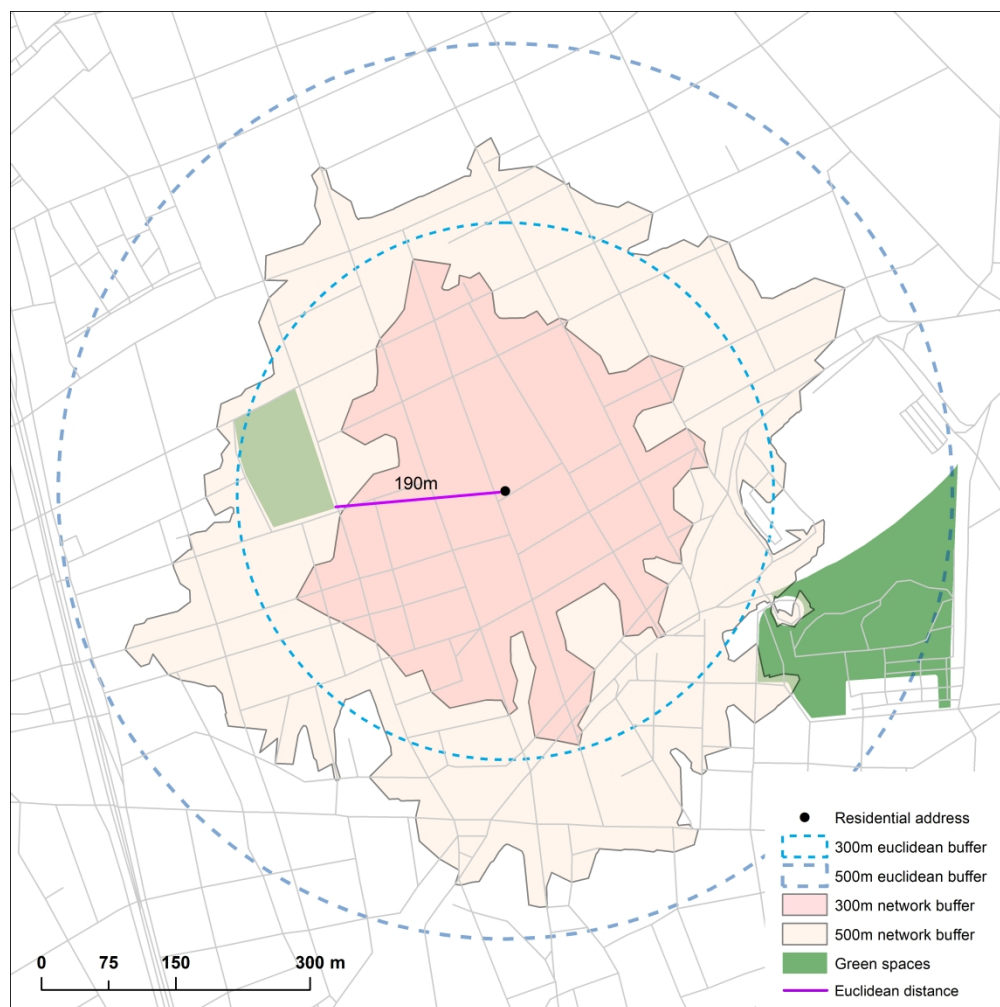


Figure 1. Example of different buffer types and the distance to natural outdoor environments from a residential address.

Supplemental Material Zijlema et al - Dog ownership, the natural outdoor environment and health: a cross-sectional study

Supplemental Table S1. Full model results of associations between dog-ownership, leisure time walking, time spent in NOE near the home, general health status and mental health.

	Leisure time walking (high vs. low)	Time spent in NOE near home (high vs. low)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
	OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)
Dog ownership (vs. not)	2.17 (1.86; 2.54)	2.37 (2.02; 2.79)	0.92 (0.73; 1.15)	0.24 (-0.89; 1.37)
Female sex	1.15 (1.00; 1.32)	0.88 (0.76; 1.01)	1.12 (0.91; 1.38)	-2.07 (-3.08; -1.07)
Age	1.01 (1.01; 1.02)	1.02 (1.01; 1.02)	0.97 (0.96; 0.98)	0.07 (0.03; 0.11)
Household composition (vs. alone)				
<i>with partner (without children)</i>	1.04 (0.84; 1.28)	0.99 (0.80; 1.24)	1.01 (0.75; 1.37)	1.36 (-0.13; 2.85)
<i>with children <12 yr old</i>	0.87 (0.66; 1.14)	1.55 (1.18; 2.05)	0.88 (0.57; 1.36)	2.86 (0.95; 4.76)
<i>with children >12 yr old</i>	0.88 (0.69; 1.13)	1.12 (0.87; 1.44)	1.00 (0.70; 1.45)	1.77 (0.05; 3.49)
<i>other</i>	0.99 (0.76; 1.29)	1.31 (0.99; 1.74)	0.57 (0.39; 0.85)	1.16 (-0.75; 3.07)
Education (vs. low)				
<i>medium</i>	1.72 (1.26; 2.36)	1.41 (1.02; 1.95)	0.99 (0.65; 1.49)	3.70 (1.55; 5.84)
<i>high</i>	2.12 (1.54; 2.93)	1.15 (0.85; 1.54)	1.26 (0.81; 1.97)	4.91 (-2.69; 7.12)
Perceived income situation (vs. cannot make ends meet)				
<i>enough to get by</i>	0.79 (0.62; 1.00)	1.12 (0.63; 1.08)	1.67 (1.19; 2.35)	2.92 (1.22; 4.63)
<i>comfortable</i>	0.88 (0.68; 1.13)	1.15 (0.89; 1.50)	5.00 (3.40; 7.36)	8.06 (6.26; 9.86)
Physical constraint restricting mobility (vs. not)	1.04 (0.88; 1.25)	0.90 (0.75; 1.09)	0.48 (0.39; 0.61)	-0.86 (-2.14; 0.41)
One or more chronic diseases (vs. not)	1.19 (1.01; 1.40)	0.85 (0.72; 1.01)	0.18 (0.14; 0.22)	-4.16 (-5.34; -2.98)
Perceived safety of NOE in NBH (vs. very satisfied)				
<i>satisfied</i>	1.10 (0.85; 1.44)	0.83 (0.63; 1.08)	1.01 (0.66; 1.56)	-2.47 (-4.33; -0.61)
<i>neutral</i>	1.10 (0.83; 1.48)	0.68 (0.51; 0.92)	0.72 (0.46; 1.15)	-4.65 (-6.70; -2.61)
<i>dissatisfied</i>	1.31 (0.97; 1.78)	0.74 (0.54; 1.01)	0.61 (0.38; 0.97)	-5.45 (-7.62; -3.28)
<i>very dissatisfied</i>	1.45 (0.92; 2.30)	0.73 (0.45; 1.17)	0.70 (0.36; 1.37)	-6.01 (-9.28; -2.73)
NBH SES (vs. low)				
<i>medium</i>	1.08 (0.87; 1.34)	1.05 (0.79; 1.39)	0.92 (0.45; 1.88)	-0.49 (-2.63; 1.64)
<i>high</i>	1.24 (0.99; 1.55)	1.15 (0.85; 1.54)	0.96 (0.46; 1.99)	0.89 (-1.33; 3.10)

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval; NBH= neighborhood; SES= socioeconomic status. Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

Supplemental Material Zijlema et al - Dog ownership, the natural outdoor environment and health: a cross-sectional study

Supplemental Table S2. Associations between dog-ownership, walking, time in NOE, perceived general and mental health status by access to NOE and residential surrounding greenness

Dog ownership (vs. not)	Leisure time walking (high vs. low)	Time spent in NOE near home (high vs. low)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)	
	OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)	
Number of NOE	300m				
	lowest	2.11 (1.76; 2.54) n=2141	2.42 (1.99; 2.94) n=2368	0.87 (0.66; 1.15) n=2414	0.37 (-0.99; 1.73) n=2412
	highest	2.36 (1.77; 3.15) n=1172	2.32 (1.73; 3.12) n=1162	0.84 (0.54; 1.29) n=1172	0.38 (-1.62; 2.39) n=1172
	1000m				
	lowest	2.17 (1.75; 2.69) n=1869	2.47 (1.98; 3.09) n=1843	0.85 (0.61; 1.18) n=1869	-0.72 (-2.24; 0.81) n=1867
	highest	2.20 (1.75; 2.76) n=1717	2.32 (1.82; 2.95) n=1687	0.87 (0.63; 1.22) n=1717	0.68 (-0.98; 2.34) n=1717
Area of NOE	300m				
	lowest	2.24 (1.80; 2.79) n=1832	2.34 (1.87; 2.94) n=1801	0.78 (0.56; 1.08) n=1832	-0.30 (-1.90; 1.30) n=1830
	highest	2.15 (1.72; 2.70) n=1754	2.43 (1.92; 3.08) n=1729	0.92 (0.65; 1.28) n=1754	0.61 (-0.97; 2.20) n=1754
	1000m				
	lowest	2.19 (1.74; 2.77) n=1799	2.31 (1.83; 2.92) n=1777	0.74 (0.53; 1.03) n=1799	-0.80 (-2.46; 0.87) n=1797
	highest	2.18 (1.76; 2.71) n=1787	2.44 (1.94; 3.07) n=1753	0.94 (0.67; 1.30) n=1787	0.65 (-0.88; 2.18) n=1787
Surrounding greenness (NDVI)	100m				
	lowest	2.10 (1.67; 2.63) n=1797	2.47 (1.96; 3.12) n=1769	0.74 (0.53; 1.03) n=1797	0.23 (-1.42; 1.89) n=1796
	highest	2.26 (1.81; 2.81) n=1789	2.32 (1.84; 2.92) n=1761	0.95 (0.68; 1.33) n=1789	-0.06 (-1.59; 1.47) n=1788
	300m				
	lowest	1.95 (1.56; 2.44) n=1786	2.33 (1.84; 2.95) n=1757	0.77 (0.54; 1.09) n=1786	0.43 (-1.25; 2.10) n=1785
	highest	2.44 (1.96; 3.04) n=1800	2.50 (1.99; 3.16) n=1773	0.98 (0.71; 1.36) n=1800	-0.11 (-1.62; 1.41) n=1799

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval; NDVI= normalized difference vegetation index. Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

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

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

		cases and controls was addressed	
		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	
		(e) Describe any sensitivity analyses	10-11
Results			Appears in manuscript on page
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	-
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	-
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	n.a.
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	n.a.
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	n.a.
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	Table 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Tables, 11-12
		(b) Report category boundaries when continuous variables were categorized	Tables, 7-10
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n.a.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Tables, 12-13
Discussion			
Key results	18	Summarise key results with reference to study objectives	13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	13-14
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	4-5

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3 *Give information separately for cases and controls in case-control studies and, if applicable, for exposed and
4 unexposed groups in cohort and cross-sectional studies.
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6 **Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and
7 published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely
8 available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at
9 <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is
10 available at www.strobe-statement.org.
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Dog ownership, the natural outdoor environment and health: a cross-sectional study

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3 Title4
5 Dog ownership, the natural outdoor environment and health: a cross-sectional study
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Abstract

Objectives

Dog owners walking their dog in natural outdoor environments (NOE) may benefit from the physical activity facilitated by dog walking and from time spent in nature. However, it is unclear whether dog owners receive additional health benefits associated with having access to NOE above the physical activity benefit of walking with their dog. We investigated associations between dog ownership, walking, time spent in NOE, and health and whether these associations differed among those with good and poor access to NOE and those living in green and less green areas.

Design

Cross-sectional study

Setting

The Positive Health Effects of the Natural Outdoor Environment in Typical Populations in Different Regions in Europe (PHENOTYPE) project.

Participants

n=3586 adults from Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania), and Stoke-on-Trent (United Kingdom).

Data collection and analysis

We calculated access to NOE with land maps and residential surrounding greenness with satellite data. Leisure time walking, time spent in NOE, and general and mental health status were measured using validated questionnaires. Associations were estimated using multilevel analysis with a random intercept defined at the neighborhood level.

Results

Dog ownership was associated with higher rates of leisure time walking and time spending in NOE (odds ratio 2.17, 95% CI 1.86, 2.54 and 2.37, 95% CI 2.02, 2.79 respectively). These associations were stronger

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3 in those living within 300m of a NOE and in greener areas. No consistent associations were found
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5 between dog ownership and perceived general or mental health status.
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7 8 Conclusions

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10 Compared with non-dog owners, dog owners walked more and spent more time in NOE, especially those
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12 living within 300m of a NOE and in greener areas. The health implications of these relationships should
13
14 be further investigated. In a largely physically inactive society, dog walking in NOE may be a simple way
15
16 of promoting physical activity and health.
17

18 19 Strengths and limitations of this study

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- 23 • This is one of the first studies from mainland Europe, and the multi-city approach revealed
24 differences between cities concerning dog ownership and health.
25
 - 26 • The assessment of access to natural outdoor environments suitable for physical activity using
27 road network buffers was chosen to optimally capture the relation with people's walking
28 behavior.
29
 - 30 • The use of multiple exposure indicators of natural outdoor environments enabled studying these
31 exposure indicators simultaneously, and could help understand what metric best predicts the
32 health benefits associated with natural outdoor environments.
33
 - 34 • We cannot establish the direction of the observed relationships because of the cross-sectional
35 study design.
36
 - 37 • We had no detailed information about dog ownership (e.g. level of attachment, duration of dog
38 ownership, primary caretaker) and we did not know if the time spent in natural outdoor
39 environments and leisure time walking was undertaken together with the dog.
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55 Competing interests

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58 None declared
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Author's Contributions

WLZ conducted the analyses. WLZ, HC and JL drafted the manuscript. MTM, MC, MB, JM, CG, HK, WWV, SA, RG, MJN were involved in the design of and data acquisition in the PHENOTYPE study. All authors provided input on the manuscript and agreed with the final version.

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Data sharing statement

Additional data are available upon request from the corresponding author (WLZ:

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INTRODUCTION

In an urbanized world, where people spend the majority of their time indoors [1], physical inactivity is a major public health problem [2]. It not only leads to adverse health effects but it is also a large economic burden for society [3]. Physical activity behavior is influenced by many factors. Apart from individual-level factors including age, sex, and health status, the built environment is an important determinant of physical activity [4,5]. Aspects of the built environment such as the availability of parks are associated with increased physical activity, especially walking [6,7]. It is important to identify sustainable built environment interventions for increasing physical activity and improving health.

Promotion of walking could be a population-level strategy to address physical inactivity. As such, and considering the prevalence of dog ownership (e.g. 18% in the Netherlands [8]), dog walking has been identified as a simple way of promoting physical activity [9–12]. There is strong evidence to suggest that dog owners walk more often and are more physically active than non-dog owners [12–14]. This association has been observed in adults [15,16], adolescents and children [17–19], in groups with potential limited mobility such as older adults [20–22] and in people with a chronic disease [23]. Consequently, dog walking may lead to better health over time, with benefits ranging from improved wellbeing [24] to fewer doctor visits [25] and a lower risk of cardiovascular disease and mortality [26].

However, not all studies show health benefits of dog ownership [27–29] and a large proportion of dog owners do not walk their dog [30,31]. Of the various factors that influence dog walking behavior, aspects of the built environment seem to be among them [11]. Supportive environments, such as neighborhoods with parks and other types of green infrastructure, are associated with higher physical activity levels of dog owners and are important for promoting dog walking [10,11,32]. Specifically, better park access and park quality (e.g. presence of dog litter bags, water sources) were related to dog walking [11,33,34]. Not all dog owners have access to parks thus improving access to parks in residential areas could be important for facilitating dog walking, especially since local parks are a common place for dog walking [35]. Parks also provide an opportunity for nature contact. Spending time in natural outdoor environments (NOE), such as parks, has been associated with health benefits, for example through facilitating stress reduction, restoration, and social contact [36–38]. Dog owners walking their dog in NOE may benefit from the physical activity facilitated by owning a dog as well as time spent in nature. However, it is unclear whether dog owners receive additional health benefits associated with having access to NOE. According to the theories of health behavior [39] and the social ecological framework [40], identifying the environmental

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3 factors that influence health outcomes (e.g. access to NOE) could lead to potential intervention strategies
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5 that could eventually improve health.
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8 The aim of this study was to investigate the relationships between dog ownership, walking, the NOE and
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10 health. In line with above-mentioned studies and health behavior theories, we hypothesized that dog owners
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12 walk more, spend more time in NOE and are healthier than non-dog owners, and that the health benefits
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14 are more apparent in dog owners within green neighborhoods and with access to NOE compared to those
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16 in less green areas and with poor NOE access. We therefore investigated the associations between dog
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18 ownership, leisure time walking, time spent in NOE, and general and mental health status, and whether
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20 these associations differed among those with good and poor access to NOE and those living in green and
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22 less green areas.
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24 METHOD

25 26 Study design and participants 27

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29 This study analyzed data from the Positive Health Effects of the Natural Outdoor environment in Typical
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31 Populations in different regions in Europe (PHENOTYPE) project. Respondents were recruited from 30
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33 different neighborhoods in Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania), and
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35 Stoke-on-Trent (United Kingdom) [41,42]. Neighborhoods were selected to maximize variability in access
36
37 to NOE and socioeconomic status. In order to arrive at a final sample of approximately 1000 respondents
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39 per city, a random sample of 30 to 35 addresses per neighborhood were mailed with a letter explaining the
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41 purpose of the project after which they were visited by interviewers. In Doetinchem, persons were asked to
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43 send back an answer card to indicate their willingness to participate before they were visited by the
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45 interviewers; and in Kaunas, persons were approached by mail to fill out postal questionnaires. Respondents
46
47 needed to have an age between 18 and 75 years and to be able to speak the local language. Data were
48
49 collected using interview-administered questionnaires (except in Kaunas, where self-administered
50
51 questionnaires were used) at respondents' residences during May-November 2013. The study was
52
53 conducted in accordance with the Declaration of Helsinki. All respondents provided written informed
54
55 consent and study protocols were approved by local ethical committees (Parc de Salut Mar, Clinical
56
57 Research Ethics Committee reference number 2011/4206/I; Medisch Ethische Toestingscommissie UMCU
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59 reference number 12/595; Lietuvos Bioetikos Komitetas reference number 6B-12-147; Faculty of Health
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61 Sciences' Ethics Panel, no reference number).

Patient and Public Involvement

Participant and stakeholder involvement and dissemination of results was organized in multiple ways through symposia, workshops, online media channels and newsletters. Members of the public were not directly involved in the design or conception of the study.

Data

Explanatory variables

Dog ownership

Dog ownership was assessed using the question: “Do you own a dog” (yes; no).

Access to NOE was estimated with land use maps from local sources in each city (details in [42]). Only NOE that were publically available; suitable for physical activity; and at least 0.5 hectare (e.g. parks, semi-natural/natural land, formal recreation grounds) or 0.25 hectare (natural/green corridors) were selected as these were relevant for physical activity [42] and therefore potentially relevant in terms of the health benefits of NOE for dog owners. Road network buffers were chosen over circular buffers in order to capture a more realistic measure of NOE accessibility on foot [43], which may be most relevant to dog walking. We furthermore used three predetermined buffer sizes to obtain a better understanding of what distance to NOE is most beneficial to health [44]. Using GIS we constructed three indicators: (1) the number of, and (2) the total surface area NOE within road network buffers of 300m, 500m, and 1000m, and (3) the road network distance to the nearest NOE (Figure 1). The number of and area of NOE were dichotomized using the city-specific median values. Distance to nearest NOE was dichotomized using a 300m cut off according to guidelines [45].

Residential surrounding greenness was assessed using the normalized difference vegetation index (NDVI). The NDVI is a measure of vegetation and represents the photosynthetic activity in an area [42,46]. Healthy vegetation absorbs most visible light and reflects large parts of near-infrared light, while sparse vegetation reflects more visible light and less near-infrared light. Based on this distinction a value between -1 and +1 is calculated, with higher values indicating a higher density of green vegetation [46]. The NDVI was derived from Landsat 5 and 8 satellite images at a resolution of 30 m × 30 m on cloud-free images within the greenest season (April to September) in the relevant period for this study (2011-2013). Average NDVI

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3 values were calculated within (Euclidean) buffers of 100m, 300m, and 500m around the residence, as used
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5 in previous research [47,48], and dichotomized using the city-specific median value.
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8
9 (Figure 1 here)

10
11 Figure 1. Example of different buffer types and the distance to natural outdoor environments from a
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13 residential address.
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16 Outcome variables

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19 Leisure time walking

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21 Walking in leisure time was assessed by the following questions: “When thinking about a normal week in
22
23 the past month how many days per week do you walk in your leisure time” and “How much time (minutes)
24
25 per day do you spend walking in your leisure time”. These items were derived from the short questionnaire
26
27 to assess health-enhancing physical activity (SQUASH) [49]. The SQUASH is a valid measure of physical
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29 activity [49,50]. Duration and frequency of walking was multiplied to create a composite variable of
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31 minutes per week of leisure time walking. This composite variable was then dichotomized using the median
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33 (120 minutes/week) as a cut point. City-specific cut points were made for city-specific analyses (Barcelona:
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35 120 min/week; Doetinchem: 120 min/week; Kaunas: 240 min/week; and Stoke-on-Trent: 20 min/week).
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38 Time spent in NOE

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40 NOE were defined as all public and private outdoor spaces that contain ‘green’ and/or ‘blue’ natural
41
42 elements such as street trees, forests, city parks and natural parks/reserves, and also included all types of
43
44 waterbodies such as canals, ponds, creeks, rivers, beaches. Time spent in NOE was assessed using two
45
46 questions: “How often did you visit/go in the last 4 weeks on purpose to green or blue space near your
47
48 home?” (5-point response scale ranging from ‘never’ (1) to ‘almost daily’ (5)); and “How much time did
49
50 you spend in a green or blue space near your home?” (4-point response scale ranging from <1 h (1) to 6–
51
52 10 h (4)). A composite variable was created to determine the amount of time (frequency of visits multiplied
53
54 by average duration per visit) respondents spent in NOE near home per month. As frequency and duration
55
56 were assessed with questions with categorical response scales, the central value of each answer category
57
58 for frequency were multiplied with central value of each answer category for duration (e.g. 3-5 h/month
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60 was coded as 4 h/month). The composite variable was then dichotomized using the median (4 hours/month)

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3 as a cut point. City-specific cut points were made for city-specific analyses (Barcelona: 3.75 h/month;
4
5 Doetinchem: 10 h/month; Kaunas: 4 h/month; and Stoke-on-Trent: 1 h/month).

6 7 8 General health status

9
10 General health status was assessed using the question: “In general what would you say your health is?” (5
11
12 point response scale: excellent to poor), which was derived from the Medical Outcome Study Short Form
13
14 (SF-36) [51]. Scores were dichotomized into “fair or poor” (0) and “excellent, very good, and good” (1).
15
16 This single question has been found to be associated with poor health outcomes in the general population
17
18 [52,53].

19 20 21 Mental health

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23 Mental health was assessed using the Short Form Health Survey (SF-36) mental health subscale, including
24
25 five items (e.g. nervousness, depression), and is a valid and reliable measure of mental health [54].
26
27 Respondents rated the occurrence of symptoms in the past four weeks on a 6-point scale ranging from “all
28
29 of the time” (1) to “none of the time” (6). A sum score was calculated and transformed into a scale ranging
30
31 from 0 to 100 according to guidelines [51] with higher scores indicating better mental health. When ≥ 3
32
33 items were missing, respondents were excluded from the analyses, but when 1-2 items were missing,
34
35 missing values were replaced by the average score of the other items. We did this for 17 respondents.
36
37 Analyses including and excluding these 17 respondents did not alter the results.

38 39 40 Covariates and other variables

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42 Information about sociodemographic factors included sex, age, educational level (primary school or no
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44 education; secondary school/ further education (up to 18 years); university degree or higher), household
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46 composition (alone; with partner (without children); with children <12 yr old; with children >12 yr old; and
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48 other), perceived income situation (cannot make ends meet; enough to get by; comfortable), frequency of
49
50 contact with family and/or friends ((almost daily; ≥ 1 per week; 1-3 per month or less), and whether
51
52 respondents feel part of a group of friends ((totally) agree; neutral, (totally) disagree). We also included
53
54 perceived safety of neighborhood NOE (very satisfied; satisfied; neutral; dissatisfied; very dissatisfied).
55
56 Health-related factors included disability restricting mobility (yes; no), one or more chronic diseases (yes;
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58 no), body mass index (based on self reported height and weight: healthy weight ≤ 25 kg/m²; overweight 25-
59
60 30 kg/m²; obese >30 kg/m²), and smoking status (current; former; never). Neighborhood socioeconomic

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3 status (SES, low; intermediate; high) was based on country-specific data (Barcelona: deprivation index
4 based on census data 2001 [55]; Doetinchem: average monthly household income per 6-digit zip code
5 level [56]; Kaunas: neighborhood education level [57]; Stoke-on-Trent: English indices of deprivation 2010
6 [58]).
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10 11 12 13 14 Statistical analyses 15

16
17 Equivalence tests with Benjamini-Hochberg adjustments for false discovery rates (5%) [59] were used to
18 test for differences between dog owner and non-dog owner characteristics. To investigate the association
19 between dog ownership, and outcomes leisure time walking, time spent in NOE, and general and mental
20 health status, and whether these associations differed for respondents with good/poor access to NOE and
21 high/low residential surrounding greenness, we investigated:
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- 26
27 1. The associations between dog ownership, and outcomes leisure time walking, time spent in NOE,
28 general health status, and mental health.
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- 30
31 2. The associations specified at 1, stratified by NOE access (good and poor) and by residential
32 surrounding greenness (high and low) to investigate whether the associations between dog
33 ownership and the outcomes differ in these subgroups.
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38 Associations were estimated using multilevel analysis with a random intercept defined at the neighborhood
39 level. Associations with leisure time walking, time spent in NOE and general health status were estimated
40 with logistic regression because of the dichotomization of the data; and since mental health scores were
41 normally distributed, associations were estimated with linear regression. Models were adjusted for age, sex,
42 education level, household composition, perceived income situation, neighborhood SES, NOE safety,
43 disability restricting mobility, and chronic diseases and were selected because of an assumed relation with
44 dog ownership, walking, time spent in NOE and health. The main associations (as specified at 1) were also
45 estimated for the cities separately. Stratified analyses by access to NOE and residential surrounding
46 greenness were undertaken with indicators in all buffer sizes, but the 500m buffer was reported in the main
47 table and the remaining buffer sizes in the Supplement. Analyses were based on complete cases (missing
48 data differed by outcome and ranged between n=360 and 416). All analyses were performed in STATA
49 14.2 [60].
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3 Sensitivity analyses were undertaken to investigate whether additional adjustment for covariates changed
4 the associations. Additional adjustments were carried out for characteristics that were found to differ
5 between dog owners and non-dog owners and that may relate to health (smoking and BMI), or that have
6 been found to be mediators of the dog ownership-health relationship (frequency of contact with family
7 and/or friends, and whether respondents feel part of a group of friends) [61,62].
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For peer review only

RESULTS

Population characteristics

Respondents were on average 51.4 (SD 15.9) years old and 54.9% were female. A total of 1109 (30.9%) respondents were dog owners. Dog owners compared with non-dog owners were on average the same age, had similar educational attainment but more were female (59.6% vs. 53.3%) and reported lower perceived income security. Dog ownership varied across cities, with it being highest in Kaunas (41.1%) and lowest in Doetinchem (16.5%). Dog owners walked more and spent more time in NOE compared with non-dog owners. However, dog owners had a lower perceived general and mental health status compared with non-dog owners. Dog owners also reported more frequently that physical constraints restricted their mobility, had more often a chronic disease, and had higher BMI than non-dog owners (Table 1).

(Table 1 here)

Dog ownership, leisure time walking, time spent in NOE and health

Adjusted multilevel models showed that dog ownership was associated with increased odds of walking ≥ 121 minutes per week (i.e. higher than the median amount of walking) (odds ratio [OR]= 2.17, 95% CI 1.86, 2.54) compared with non-dog owners. Dog ownership was also associated with increased odds of spending ≥ 4 hours/month in NOE (i.e. higher than the median amount of time in NOE) (OR= 2.37, 95% CI 2.02, 2.79) compared with non-dog owners. There were no differences in perceived general health status and mental health between dog owners and non-dog owners. City-specific analyses showed similar results, with some exceptions: a positive association between dog ownership and perceived general health in Barcelona (OR=1.90, 95% CI 1.01, 3.56); and a positive association between dog ownership and mental health in Stoke-on-Trent (β = 2.61, 95% CI 0.35, 4.86) (Table 2 and Supplemental Table S1).

(Table 2 here)

Stratified analyses by access to NOE and residential surrounding greenness

Generally, stratified analyses showed that the associations between dog ownership and leisure time walking by number and area of NOE were similar. The odds ratio for dog ownership and leisure time walking was larger for those living within 300m of a NOE (OR= 2.36, 95% CI 1.97, 2.83) compared to those living within >300m of a NOE (OR= 1.86, 95% CI 1.36, 2.55; Table 3). Similar results were observed for those

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2
3 with a high amount of residential surrounding greenness (100 and 300m buffer, Supplemental Table S2)
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5 compared to low residential surrounding greenness.
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8 The associations between dog ownership and time spent in NOE were larger for those with a lower number
9
10 or area of NOE than for those with a higher number or area of NOE (Table 3 and Supplemental Table S2).
11
12 We observed a larger odds ratio for the association between dog ownership and time spent in NOE for those
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14 living within 300m of a NOE (OR= 2.64, 95% CI 2.18, 3.20) compared to those living within >300m of a
15
16 NOE (OR= 1.82, 95% CI 1.31, 2.55; Table 3). A larger odds ratio for the association between dog
17
18 ownership and time spent in NOE for those with more residential surrounding greenness were consistent
19
20 across buffer sizes 300m and 500m, but not for residential surrounding greenness within 100m (Table 3
21
22 and Supplemental Table S2).
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25 There were no statistically significant associations between dog ownership and perceived general health
26
27 status when stratifying by access to NOE or residential surrounding greenness. Similarly, there was no
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29 indication for an association between dog ownership and mental health in groups with high or low access
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31 to NOE and with high or low residential surrounding greenness (Table 3).
32

33 (Table 3 here)
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38 Sensitivity analysis
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41 Additional adjustments for smoking, BMI, frequency of contact with family and/or friends, and whether
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43 respondents feel part of a group of friends, did not change the results (results available upon request).
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48 DISCUSSION 49

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51 Having a dog was associated with more leisure time walking and time spent in NOE near home compared
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53 with not having a dog. Moreover, the differences in walking and time spent in NOE between dog owners
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55 and non-dog owners were larger when there was a NOE within 300m of the residence, and a high amount
56
57 of residential surrounding greenness. There was no consistent evidence for an association between dog
58
59 ownership and perceived general and mental health status. Only dog owners from Stoke-on-Trent had better
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3 mental health compared with non-dog owners, and dog owners from Barcelona had better perceived general
4 health compared to non-dog owners.
5

6
7 Prior studies have also observed links between NOE, dog ownership and physical activity. In support of
8 our findings, a UK study of older adults reported that neighborhood greenness was associated with a smaller
9 decline in physical activity over time, and that dog walking explained up to 50% of the variance in the
10 relationship between greenness and outdoor physical activity [63]. Our findings were also consistent with
11 a Danish study that found that dog ownership was a major determinant of park visits, especially those parks
12 closest to the residence [35]. Our study adds to the evidence base by including multiple exposure indicators
13 of NOE which enabled studying multiple exposure indicators of NOE simultaneously, and could help
14 understand what metric best predicts the health benefits associated with NOE [36,37,41]. We found that
15 dog owners spent more time in NOE than non-dog owners, but dog ownership was not consistently related
16 to perceived mental or general health status. Dog ownership was only related to better perceived general or
17 mental health in Barcelona and Stoke-on-Trent, the two cities where respondents were the least active and
18 spent the least time in NOE. This suggests that the health benefits of dog ownership exist when walking
19 and time spent in NOE is low to begin with. Because we found no consistent evidence for health benefits
20 for dog owners with better availability of NOE, future studies could also investigate subjective indicators
21 of NOE, including satisfaction and importance, and neighborhood aesthetics [64].
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37 Although the cross-sectional nature of our study does not allow for understanding the longitudinal effects
38 of dog ownership on health, it is possible that people with physical constraints and chronic diseases more
39 often decide to have a dog, for example following doctor's advice, in order to stay mobile [26]. Similarly,
40 another study reported that dog owners more often had asthma, and a higher BMI compared with non-dog
41 owners [28]. Furthermore, an Australian study found that although pet ownership was associated with
42 higher levels of physical activity, it was also associated with higher self-reported BMI, higher diastolic
43 blood pressure, and smoking [27]. We found that despite the physical constraints and chronic diseases, dog
44 owners engaged in more leisure time walking than non-dog owners. We hypothesize that the extra physical
45 activity facilitated by dog walking may offset some of the other negative health risk factors dog owners
46 have, and could eventually yield longer term health benefits. This may especially occur in green
47 neighborhoods, when there is access to NOE and when the residential environment promotes walking.
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3 Limitations of this study include the lack of information about the dog (e.g. breed, age, temperament), the
4 dog owner's level of attachment to their dog, the duration of dog ownership, and if the respondent was the
5 primary carer of the dog. Such factors may have influenced the potential health benefits of dog ownership,
6 but we were unable to take these factors into account. We further did not know if the time spent in NOE
7 and leisure time walking was undertaken together with the dog, and whether time spent in NOE was time
8 spent walking. Future research should measure specific aspects of dog ownership and should use measures
9 of behavior such as time spent in NOE with and without dog and leisure time walking undertaken with and
10 without the dog. A limitation of self-reporting walking habits is potential overstatement of the amount of
11 walking. Minutes of walking and time in NOE were dichotomized because of non-normal distributions and
12 although this resulted in easier interpretation of data, it also resulted in information loss. Although data
13 collection was similar in each city, data on neighborhood SES was based on country-specific data and this
14 might have complicated comparisons between cities. Finally, we cannot establish the direction of the
15 observed relationships because of the cross-sectional study design. For example, people who are already
16 physically active and visit NOE may decide to get a dog, instead of dogs motivating their owners to walk
17 and visit NOE more. Strengths include the multi-city approach, which revealed differences between cities
18 concerning dog ownership and health. It is also one of the first studies from mainland Europe, since the
19 majority of research has been carried out in North America, Australia, and in the UK. More international
20 studies about dog ownership and health are needed. Finally, our measure of access to NOE was specific to
21 environments that were suitable for physical activity. Also, for access to NOE, we used road network
22 buffers over circular buffers which better capture people's walking behavior; and we used varying buffer
23 sizes to obtain a better understanding of what distance to NOE is most beneficial to health [44].

24 Conclusions

25
26 Dog owners performed more leisure time walking and spent more time in NOE compared with non-dog
27 owners, especially when they lived within 300m of a NOE and when they lived in green areas. There was
28 no consistent relationship between dog ownership and better perceived general or mental health status. In
29 a largely physically inactive society where many people remain indoors, dog walking in parks or other NOE
30 may be an opportunity to engage people in walking behavior as a path towards better health. Cities should
31 therefore ensure that there is access to NOE for dog owners and provide green infrastructure in order to
32 promote dog walking. Future research should focus on natural experiments and evaluation of intervention
33 strategies to increase dog owners' access to NOE.

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Tables.

Table 1. Population characteristics by dog-ownership

	Total n=3586	Non-dog- owner n=2478	Dog owner n=1108	adjusted p-value*
Age, mean (SD)	51.4 (15.9)	51.3 (15.9)	51.7 (16.0)	0.474
Sex, n (females %)	1967 (54.9)	1314 (53.0)	653 (58.9)	0.001
Household composition, n (%)				0.001
<i>alone</i>	614 (17.1)	461 (18.6)	153 (13.8)	
<i>with partner (without children)</i>	1239 (34.5)	864 (34.9)	375 (33.8)	
<i>with children <12 yr old</i>	535 (14.9)	383 (15.5)	152 (13.7)	
<i>with children >12 yr old</i>	602 (16.8)	368 (14.9)	234 (21.1)	
<i>other</i>	597 (16.6)	402 (16.2)	195 (17.6)	
City, n (%)				0.001
<i>Barcelona</i>	979 (27.3)	790 (31.9)	189 (17.1)	
<i>Doetinchem</i>	851 (23.7)	668 (27.0)	183 (16.5)	
<i>Kaunas</i>	892 (24.9)	436 (17.6)	456 (41.1)	
<i>Stoke-on-Trent</i>	864 (24.1)	584 (23.6)	280 (25.3)	
Education, n (%)				0.530
<i>low</i>	251 (7.0)	163 (6.6)	88 (7.9)	
<i>medium</i>	1568 (43.7)	1087 (43.9)	481 (43.5)	
<i>high</i>	1767 (49.3)	1228 (49.6)	539 (48.6)	
Perceived income situation, n (%)				0.001
<i>cannot make ends meet</i>	385 (10.7)	276 (11.1)	109 (9.8)	
<i>enough to get by</i>	1800 (50.2)	1165 (47.0)	635 (57.3)	
<i>comfortable</i>	1401 (39.1)	1037 (41.9)	364 (32.9)	
Weight status (BMI categories), n (%)				0.001
<i>healthy weight</i>	1610 (44.9)	1165 (47.0)	445 (40.2)	
<i>overweight</i>	1192 (33.2)	819 (33.1)	373 (33.6)	
<i>obese</i>	784 (21.9)	494 (19.9)	290 (26.2)	
Physical constraint restricting mobility, n (%)	1003 (25.4)	536 (19.9)	467 (37.3)	0.001
One or more chronic diseases, n (%)	1313 (36.6)	860 (34.7)	453 (40.9)	0.001
Smoking, n (%)				0.020
<i>current</i>	733 (20.5)	478 (19.3)	255 (23.0)	
<i>former</i>	1008 (28.1)	724 (29.2)	284 (25.6)	
<i>never</i>	1843 (51.4)	1275 (51.5)	568 (51.3)	
Frequency of contact with family and/or friends, n (%)				0.299
<i>(almost) daily</i>	2135 (59.5)	1470 (59.3)	665 (60.0)	
<i>≥1 per week</i>	1114 (31.1)	781 (31.1)	333 (30.0)	
<i>1-3 per month or less</i>	392 (9.4)	227 (9.2)	111 (10.0)	
Feeling part of a group of friends, n %				0.001
<i>(totally) agree</i>	2414 (67.5)	1754 (70.9)	660 (59.7)	
<i>neutral, (totally) disagree</i>	1165 (32.5)	719 (29.1)	446 (40.3)	
Perceived safety of NOE in NBH, n (%)				0.016
<i>(very) satisfied</i>	2123 (59.2)	1486 (60.0)	637 (57.5)	
<i>neutral</i>	776 (21.6)	542 (21.9)	234 (21.1)	
<i>(very) dissatisfied</i>	687 (19.2)	450 (18.2)	237 (21.4)	
NBH SES, n (%)				0.474
<i>low</i>	1131 (31.5)	791 (31.9)	340 (30.7)	
<i>medium</i>	1379 (38.4)	938 (37.9)	441 (39.8)	
<i>high</i>	1076 (30.0)	749 (30.2)	327 (29.5)	

Minutes/week walking (leisure), median (IQR)	120 (300)	90 (240)	180 (420)	0.001
Hours spent in NOE near home in last 4 wks, median (IQR)	4 (11.8)	3.75 (10)	10 (29.3)	0.001
General health, n (%)				0.001
<i>Excellent</i> , (very) good	2662 (74.2)	1939 (78.3)	723 (65.2)	
<i>(very) Bad</i>	924 (25.8)	539 (21.8)	385 (34.8)	
Mental health (SF-36), mean (SD)	73.5 (16.3)	73.9 (16.2)	72.5 (16.3)	0.01
Distance to nearest NOE (m), median (IQR)	161.0 (214)	155.7 (205.6)	172.4 (232.4)	0.001
Number of NOE in 300m NWB, median (IQR)	1 (1)	1 (2)	1 (2)	0.001
Number of NOE in 500m NWB, median (IQR)	1 (1)	3 (3)	3 (3)	0.001
Number of NOE in 1000m NWB, median (IQR)	10 (10)	11 (10)	8 (10)	0.001
Area of NOE in 300m NWB (m ²), median (IQR)	38,013 (136,092)	36,007 (132,239)	41,241 (154,377)	0.58
Area of NOE in 500m NWB (m ²), median (IQR)	140,281 (286,917)	137,862 (261,453)	150,758 (402,966)	0.03
Area of NOE in 1000m NWB (m ²), median (IQR)	588,516 (975,551)	557,191 (890,303)	720,366 (239,293)	0.001
Distance to nearest NOE (m), median (IQR)	161.0 (214)	155.7 (205.6)	172.4 (232.4)	0.001
Average residential surrounding greenness in 100m buffer, median (IQR)	0.46 (0.16)	0.44 (0.28)	0.50 (0.16)	0.001
Average residential surrounding greenness in 300m buffer, median (IQR)	0.49 (0.23)	0.47 (0.30)	0.51 (0.13)	0.001
Average residential surrounding greenness in 500m buffer, median (IQR)	0.49 (0.23)	0.48 (0.31)	0.51 (0.11)	0.001

NOE= natural outdoor environments; NBH= neighborhood; NWB= network buffer; IQR= interquartile range; SD= standard deviation; BMI= body mass index; SES= socioeconomic status. * based on t-tests, Chi-square, Kruskal-Wallis, and rank-sum tests and with p-values adjusted for the false discovery rate with the Benjamini-Hochberg Procedure.

Table 2. Associations between dog-ownership, leisure time walking, time spent in NOE near the home, general health status and mental health.

	Leisure time walking (high vs. low)	Time spent in NOE near home (high vs. low)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
Dog ownership (vs. not)	OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)
Total	2.17 (1.86; 2.54) n=3586	2.37 (2.02; 2.79) n=3530	0.92 (0.73; 1.15) n=3586	0.24 (-0.89; 1.37) n=3584
Barcelona	1.46 (1.03; 2.08) n=979	2.14 (1.47; 3.13) n=978	1.90 (1.01; 3.56) n=979	0.13 (-2.29; 2.55) n=979
Doetinchem	7.97 (5.18; 12.25) n=851	1.18 (0.80; 1.73) n=846	0.89 (0.37; 2.17) n=851	1.61 (-0.55; 3.78) n=849
Kaunas	1.05 (0.79; 1.39) n=892	1.26 (0.93; 1.69) n=844	0.71 (0.50; 1.00) n=892	-2.17 (-4.40; 0.06) n=892
Stoke-on-Trent	2.01 (1.44; 2.79) n=864	2.31 (1.63; 3.27) n=862	0.89 (0.57; 1.37) n=864	2.61 (0.35; 4.86) n=864

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval

Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

Table 3. Associations between dog-ownership, walking, time in NOE, perceived general and mental health status stratified by access to NOE and residential surrounding greenness.

		Leisure time walking (high vs. low)	Time spent in NOE near home (high vs. low)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
Dog ownership (vs. not)		OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)
Number of NOE (500m)	lowest	2.13 (1.74; 2.62) n=2084	2.57 (2.07; 3.17) n=2051	0.89 (0.65; 1.22) n=2084	0.55 (-0.93; 2.03) n=2082
	highest	2.29 (1.79; 2.94) n=1502	2.23 (1.72; 2.89) n=1479	0.90 (0.62; 1.29) n=1502	-0.62 (-2.36; 1.13) n=1502
Area of NOE (500m)	lowest	2.36 (1.88; 2.97) n=1779	2.53 (2.00; 3.20) n=1753	0.90 (0.64; 1.27) n=1779	0.85 (-0.83; 2.53) n=1777
	highest	2.04 (1.64; 2.53) n=1807	2.19 (1.75; 2.75) n=1777	0.81 (0.59; 1.12) n=1807	-0.48 (-1.20; 1.04) n=1807
Distance to nearest NOE	≤ 300 m	2.36 (1.97; 2.83) n=2778	2.64 (2.18; 3.20) n=2746	0.91 (0.69; 1.20) n=2778	0.66 (-0.61; 1.93) n=2776
	> 300 m	1.86 (1.36; 2.55) n=808	1.82 (1.31; 2.55) n=784	0.70 (0.46; 1.05) n=808	-1.05 (-3.45; 1.36) n=808
Residential surrounding greenness (500m)	lowest	2.15 (1.70; 2.71) n=1786	2.29 (1.81; 2.91) n=1765	0.86 (0.61; 1.21) n=1786	0.38 (-1.29; 2.05) n=1785
	highest	2.19 (1.77; 2.72) n=1800	2.57 (2.04; 3.24) n=1765	0.95 (0.68; 1.33) n=1800	-0.16 (-1.69; 1.36) n=1799

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval. *Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.*

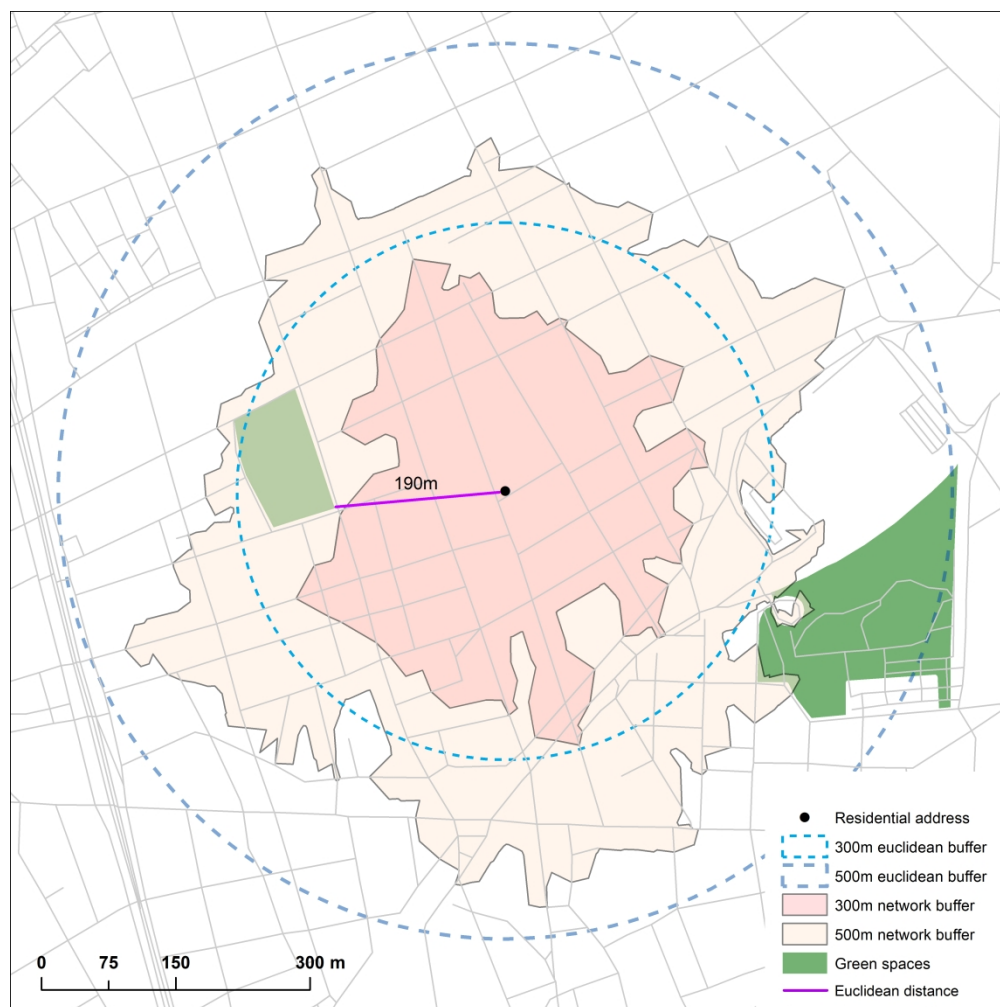


Figure 1. Example of different buffer types and the distance to natural outdoor environments from a residential address.

Supplemental Material Zijlema et al - Dog ownership, the natural outdoor environment and health: a cross-sectional study

Supplemental Table S1. Full model results of associations between dog-ownership, leisure time walking, time spent in NOE near the home, general health status and mental health.

	Leisure time walking (high vs. low)	Time spent in NOE near home (high vs. low)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)
	OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)
Dog ownership (vs. not)	2.17 (1.86; 2.54)	2.37 (2.02; 2.79)	0.92 (0.73; 1.15)	0.24 (-0.89; 1.37)
Female sex	1.15 (1.00; 1.32)	0.88 (0.76; 1.01)	1.12 (0.91; 1.38)	-2.07 (-3.08; -1.07)
Age (per 10 years)	1.13 (1.07; 1.00)	1.18 (1.11; 1.26)	0.75 (0.68; 0.82)	0.70 (0.29; 1.12)
Household composition (vs. alone)				
<i>with partner (without children)</i>	1.04 (0.84; 1.28)	0.99 (0.80; 1.24)	1.01 (0.75; 1.37)	1.36 (-0.13; 2.85)
<i>with children <12 yr old</i>	0.87 (0.66; 1.14)	1.55 (1.18; 2.05)	0.88 (0.57; 1.36)	2.86 (0.95; 4.76)
<i>with children >12 yr old</i>	0.88 (0.69; 1.13)	1.12 (0.87; 1.44)	1.00 (0.70; 1.45)	1.77 (0.05; 3.49)
<i>other</i>	0.99 (0.76; 1.29)	1.31 (0.99; 1.74)	0.57 (0.39; 0.85)	1.16 (-0.75; 3.07)
p for trend	0.420	0.051	0.017	0.228
Education (vs. low)				
<i>medium</i>	1.72 (1.26; 2.36)	1.41 (1.02; 1.95)	0.99 (0.65; 1.49)	3.70 (1.55; 5.84)
<i>high</i>	2.12 (1.54; 2.93)	1.15 (0.85; 1.54)	1.26 (0.81; 1.97)	4.91 (2.69; 7.12)
p for trend	<0.001	0.192	0.052	<0.001
Perceived income situation (vs. cannot make ends meet)				
<i>enough to get by</i>	0.79 (0.62; 1.00)	1.12 (0.63; 1.08)	1.67 (1.19; 2.35)	2.92 (1.22; 4.63)
<i>comfortable</i>	0.88 (0.68; 1.13)	1.15 (0.89; 1.50)	5.00 (3.40; 7.36)	8.06 (6.26; 9.86)
p for trend	0.925	0.401	<0.001	<0.001
Physical constraint restricting mobility (vs. not)	1.04 (0.88; 1.25)	0.90 (0.75; 1.09)	0.48 (0.39; 0.61)	-0.86 (-2.14; 0.41)
One or more chronic diseases (vs. not)	1.19 (1.01; 1.40)	0.85 (0.72; 1.01)	0.18 (0.14; 0.22)	-4.16 (-5.34; -2.98)
Perceived safety of NOE in NBH (vs. very satisfied)				
<i>satisfied</i>	1.10 (0.85; 1.44)	0.83 (0.63; 1.08)	1.01 (0.66; 1.56)	-2.47 (-4.33; -0.61)
<i>neutral</i>	1.10 (0.83; 1.48)	0.68 (0.51; 0.92)	0.72 (0.46; 1.15)	-4.65 (-6.70; -2.61)
<i>dissatisfied</i>	1.31 (0.97; 1.78)	0.74 (0.54; 1.01)	0.61 (0.38; 0.97)	-5.45 (-7.62; -3.28)
<i>very dissatisfied</i>	1.45 (0.92; 2.30)	0.73 (0.45; 1.17)	0.70 (0.36; 1.37)	-6.01 (-9.28; -2.73)
p for trend	0.037	0.032	0.001	<0.001
NBH SES (vs. low)				
<i>medium</i>	1.08 (0.87; 1.34)	1.05 (0.79; 1.39)	0.92 (0.45; 1.88)	-0.49 (-2.63; 1.64)
<i>high</i>	1.24 (0.99; 1.55)	1.15 (0.85; 1.54)	0.96 (0.46; 1.99)	0.89 (-1.33; 3.10)
p for trend	0.055	0.382	0.944	0.353

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval; NBH= neighborhood; SES= socioeconomic status. Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

Supplemental Material Zijlema et al - Dog ownership, the natural outdoor environment and health: a cross-sectional study

Supplemental Table S2. Associations between dog-ownership, walking, time in NOE, perceived general and mental health status stratified by access to NOE and residential surrounding greenness

Dog ownership (vs. not)	Leisure time walking (high vs. low)	Time spent in NOE near home (high vs. low)	General health, excellent, (very) good (reference: fair, poor)	Mental health (scale 0-100, higher is better)	
	OR (95% CI)	OR (95% CI)	OR (95% CI)	β (95% CI)	
Number of NOE	300m				
	lowest	2.11 (1.76; 2.54) n=2141	2.42 (1.99; 2.94) n=2368	0.87 (0.66; 1.15) n=2414	0.37 (-0.99; 1.73) n=2412
	highest	2.36 (1.77; 3.15) n=1172	2.32 (1.73; 3.12) n=1162	0.84 (0.54; 1.29) n=1172	0.38 (-1.62; 2.39) n=1172
	1000m				
	lowest	2.17 (1.75; 2.69) n=1869	2.47 (1.98; 3.09) n=1843	0.85 (0.61; 1.18) n=1869	-0.72 (-2.24; 0.81) n=1867
	highest	2.20 (1.75; 2.76) n=1717	2.32 (1.82; 2.95) n=1687	0.87 (0.63; 1.22) n=1717	0.68 (-0.98; 2.34) n=1717
Area of NOE	300m				
	lowest	2.24 (1.80; 2.79) n=1832	2.34 (1.87; 2.94) n=1801	0.78 (0.56; 1.08) n=1832	-0.30 (-1.90; 1.30) n=1830
	highest	2.15 (1.72; 2.70) n=1754	2.43 (1.92; 3.08) n=1729	0.92 (0.65; 1.28) n=1754	0.61 (-0.97; 2.20) n=1754
	1000m				
	lowest	2.19 (1.74; 2.77) n=1799	2.31 (1.83; 2.92) n=1777	0.74 (0.53; 1.03) n=1799	-0.80 (-2.46; 0.87) n=1797
	highest	2.18 (1.76; 2.71) n=1787	2.44 (1.94; 3.07) n=1753	0.94 (0.67; 1.30) n=1787	0.65 (-0.88; 2.18) n=1787
Surrounding greenness (NDVI)	100m				
	lowest	2.10 (1.67; 2.63) n=1797	2.47 (1.96; 3.12) n=1769	0.74 (0.53; 1.03) n=1797	0.23 (-1.42; 1.89) n=1796
	highest	2.26 (1.81; 2.81) n=1789	2.32 (1.84; 2.92) n=1761	0.95 (0.68; 1.33) n=1789	-0.06 (-1.59; 1.47) n=1788
	300m				
	lowest	1.95 (1.56; 2.44) n=1786	2.33 (1.84; 2.95) n=1757	0.77 (0.54; 1.09) n=1786	0.43 (-1.25; 2.10) n=1785
	highest	2.44 (1.96; 3.04) n=1800	2.50 (1.99; 3.16) n=1773	0.98 (0.71; 1.36) n=1800	-0.11 (-1.62; 1.41) n=1799

NOE= natural outdoor environments; OR= odds ratio; CI= confidence interval; NDVI= normalized difference vegetation index. Analytical method: mixed models with random intercept for neighborhoods and adjusted for age, sex, education, neighborhood SES, household composition, perceived income situation, perceived NOE safety, physical constraint restricting mobility, and chronic diseases. Analyses were based on complete cases.

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

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

		cases and controls was addressed	
		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	
		(e) Describe any sensitivity analyses	10-11
Results			Appears in manuscript on page
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	-
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	-
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	n.a.
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	n.a.
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	n.a.
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	Table 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Tables, 11-12
		(b) Report category boundaries when continuous variables were categorized	Tables, 7-10
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n.a.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Tables, 12-13
Discussion			
Key results	18	Summarise key results with reference to study objectives	13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	13-14
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	4-5

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2
3 *Give information separately for cases and controls in case-control studies and, if applicable, for exposed and
4 unexposed groups in cohort and cross-sectional studies.
5

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