BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023000
Article Type:	Research
Date Submitted by the Author:	22-Mar-2018
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Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, MENTAL HEALTH

Title

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

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

Strengths and limitations

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

Competing interests

None declared

Funding

This work was supported by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 282996. W.L. Zijlema is supported by a Sara Borrell grant from the Instituto de Salud Carlos III (CD17/00195). H. Christian is supported by an Australian National Heart

Foundation Future Leader Fellowship (#100794). ISGlobal is a member of the CERCA Programme, Generalitat de Catalunya. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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. The authors thank the PHENOTYPE respondents for their contribution.

Data sharing statement

Additional data are available upon request from the corresponding author (WLZ: Wilma.zijlema@isglobal.org).

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

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 [36,37]. 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 [37]. 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 values were calculated within (Euclidean) buffers of 100m, 300m, and 500m around the residence, as used in previous research [38,39], and dichotomized using the median value.

Access to NOE was estimated with land use maps from local sources in each city. 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 [36] 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 [40], which may be most relevant to dog walking. We furthermore used varying buffer sizes to obtain a better understanding of what distance to NOE is most beneficial to health [41]. 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, all dichotomized using the median values.

Covariates and other variables

Information about sociodemographic factors included sex, age, educational level (primary school or no education; secondary school/ further education (up to 18 years); university degree or higher), household composition (alone; with partner (without children); with children <12 yr old; with children >12 yr old; and other), perceived income situation (cannot make ends meet; enough to get by; comfortable), frequency of contact with family and/or friends ((almost daily; ≥1 per week; 1-3 per month or less), and whether respondents feel part of a group of friends ((totally) agree; neutral, (totally) disagree). Home-related factors included perceived safety of neighborhood NOE (very satisfied; satisfied; neutral; dissatisfied; very dissatisfied), home ownership (yes; no), crowding index (rooms/person), housing type (detached; semi-detached; flat; other), and yard access (yes; no). Health-related factors included disability

restricting mobility (yes; no), one or more chronic diseases (yes; no), body mass index (based on self reported height and weight: healthy weight ≤25 kg/m^2; overweight 25-30 kg/m^2; obese >30 kg/m^2), and smoking status (current; former; never). Neighborhood socioeconomic status (SES, low; intermediate; high) was based on country-specific data (Barcelona: deprivation index based on census data 2001 [42]; Doetinchem: average monthly household income per 6-digit zip code level [43]; Kaunas: neighborhood education level [44]; Stoke-on-Trent: English indices of deprivation 2010 [45]).

Statistical analyses

Equivalence tests were used to test for differences between dog owner and non-dog owner characteristics. To investigate 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, we investigated:

1. The associations between dog ownership, leisure time walking, time spent in NOE, general health status, and mental health.
2. The associations specified at 1, including interaction terms between dog ownership and NOE indicators, to investigate whether these associations differed for respondents with varying exposure to NOE.
3. The associations specified at 1, stratified by NOE exposure, when the interaction term (specified at 2) had a p-value <0.05, to investigate these associations for respondents with varying exposure to NOE.

Associations were estimated using multilevel analysis with a random intercept defined at the city and neighborhood level. Models were adjusted for age, sex, education level, household composition, perceived income situation, neighborhood SES, NOE safety, disability restricting mobility, and chronic diseases and were selected because of an assumed relation with dog ownership, walking, NOE exposure and health. The main associations (as specified at 1) were also estimated for the cities separately. Analyses were based on complete cases.

Sensitivity analyses were undertaken to investigate whether adjustment for characteristics that were found to differ between dog owners and non-dog owners, and that may relate to health, changed the

associations. Models were additionally adjusted (separately and simultaneously) for smoking, BMI, frequency of contact with family and/or friends, and whether respondents feel part of a group of friends. A second sensitivity analysis was undertaken to evaluate differences between time spent in NOE near home, and in or near the city for associations specified at 2 and 3 by using two variables: time spent in NOE in the city, and time spent in NOE near the city.

RESULTS

Population characteristics

Respondents were on average 51.4 (SD 15.9) years old and 54.9% was 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) = 2.13, 95% confidence interval (CI) 1.82, 2.50) 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= 2.42, 95% CI 2.05, 2.86) compared with non-dog owners. There were no differences in 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 general health in Barcelona (OR=1.90, 95% CI 1.01, 3.56); a positive association between dog ownership and mental health in Stoke-on-Trent (OR= 2.61, 95% CI 0.35, 4.86); but no association between dog

ownership and time spent in NOE in Doetinchem. In Kaunas, there were no associations between leisure time walking and time spent in NOE by dog ownership status (Table 2).

(Table 2 here)

Interactions between dog ownership and NOE

We found indication for interaction between leisure time walking, dog ownership and number of NOE (all buffer sizes). Stratified analyses showed that dog owners with the highest number of NOE around their home had increased odds of performing ≥121 minutes per week of leisure time walking (i.e. higher than the median amount of walking) (e.g. 1000m buffer: OR= 3.54, 95% CI 2.76, 4.54) compared with non-dog owners. For those with a lower number of NOE, dog ownership was also associated with more leisure time walking, but odds ratios were smaller (e.g. 1000m buffer: OR= 1.41, 95% CI 1.14, 1.75). Similar results were observed for those with a shorter distance to the nearest NOE, and for those with a higher amount of surrounding greenness within 500m around home (Table 3).

For time spent in NOE, there was indication of interaction between dog ownership and number of NOE within 500m and 1000m of home. Stratified analyses showed that dog owners with a higher number of NOE spent more time in NOE (i.e. ≥4 hours/month or higher than the median amount of time in NOE) compared with non-dog owners (e.g. 1000m buffer: OR= 4.31, 95% CI 3.31, 5.63). In comparison, dog owners with a lower number of NOE near home also spent more time in NOE compared with non-dog owners, but the odds ratios were smaller (e.g. 1000m buffer: OR= 1.60, 95% CI 1.29, 1.99) (Table 3).

There was indication for interaction between dog ownership and NOE exposure indicators in relation to mental health for the number and area of NOE within 1000m of home and for NDVI within 300m of home. Stratified analyses showed that dog owners with the highest number of NOE within 1000m of home had better mental health compared with non-dog owners (β= 2.70, 95% CI 1.08, 4.32), but showed no association for those with a below median number of NOE. Dog ownership was associated with better mental health for those with a lower amount of surrounding greenness within 300m around home (β= 1.79, 95% CI 0.06, 3.52), but not for those with a higher amount of surrounding greenness (Table 3). There were no associations between dog ownership and mental health, stratified by area of NOE within 1000m of home. Finally, there was no indication for interaction between dog ownership and NOE exposure indicators in relation to general health status.

(Table 3 here)

Sensitivity analysis

Additional adjusted for smoking, BMI, frequency of contact with family and/or friends, and whether respondents feel part of a group of friends, did not change the results (results available upon request). Furthermore, there was no indication for interaction between dog ownership and time spent in NOE in and near the city (results available upon request).

DISCUSSION

Having a dog was associated with more leisure time walking and time spent in NOE near home compared with not having a dog. Moreover, the differences in walking and time spent in NOE between dog owners and non-dog owners were larger when there were more NOE near home. There was no consistent evidence for an association between dog ownership and general and mental health status. Only dog owners from Stoke-on-Trent had better mental health compared with non-dog owners, and dog owners from Barcelona had better general health compared to non-dog owners.

Prior studies have also observed links between NOE, dog ownership and physical activity. In support of our findings, a UK study of older adults reported that neighborhood greenness was associated with a smaller decline in physical activity over time, and that dog walking explained up to 50% of the variance in the relationship between greenness and outdoor physical activity [46]. Our findings were also consistent with a Danish study that found that dog ownership was a major determinant of park visits, especially those parks closest to the residence [25]. Our study adds to the evidence base by including multiple exposure indicators of NOE which enabled studying multiple exposure indicators of NOE simultaneously, and could help understand what metric best predicts the health benefits associated with NOE [26,27,29]. We found that dog owners spent more time in NOE than non-dog owners, but dog ownership was not consistently related to mental or general health status. Dog ownership was only related to better general or mental health in Barcelona and Stoke-on-Trent, the two cities where respondents were the least active and spent the least time in NOE, and may indicate that health benefits of dog ownership

exist when walking and time spent in NOE is low to begin with. Because we found no consistent evidence for health benefits for dog owners with better availability of NOE, future studies could also investigate subjective indicators of NOE, including satisfaction and importance, and neighborhood aesthetics [47].

Although the cross-sectional nature of our study does not allow for understanding the longitudinal effects of dog ownership on health, it is possible that people with physical constraints and chronic diseases more often decide to have a dog, for example following doctor's advice, in order to stay mobile [22]. Similarly, another study reported that dog owners more often had asthma, and a higher BMI compared with non-dog owners [48]. Furthermore, an Australian study found that although pet ownership was associated with higher levels of physical activity, it was also associated with higher BMI, higher diastolic blood pressure, and smoking [49]. We found that despite being less healthy, dog owners engaged in about twice as much leisure time walking than non-dog owners. We hypothesize that the extra physical activity facilitated by dog walking may offset some of the other negative health risk factors dog owners have, and could eventually yield longer term health benefits. This may especially occur when there is access to NOE and the residential environment promotes walking.

Limitations of this study include the lack of information about the dog owner's level of attachment to their dog, the duration of dog ownership, and if the respondent was the primary carer of the dog. We further did not know if the time spent in NOE and leisure time walking was undertaken together with the dog, and whether time spent in NOE was time spent walking. Future research should measure specific aspects of dog ownership and should use measures of behavior such as time spent in NOE with and without dog and leisure time walking undertaken with and without the dog. A limitation of self-reporting walking habits is potential overstatement of the amount of walking. Finally, we cannot establish the direction of the observed relationships because of the cross-sectional study design. For example, people who are already physically active and visit NOE may decide to get a dog, instead of dogs motivating their owners to walk and visit NOE more. Strengths include the multi-city approach, which revealed differences between cities concerning dog ownership and health. It is also one of the first studies from mainland Europe, since the majority of research has been carried out in North America, Australia, and in the UK. Finally, our measure of access to NOE was specific to environments that were suitable for physical activity. We also used road network buffers over circular buffers which better capture people's walking behavior; and we used varying buffer sizes to obtain a better understanding of what distance to NOE is most beneficial to health [41].

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
alone	614 (17.1)	461 (18.6)	153 (13.8)	
with partner (without children)	1239 (34.5)	864 (34.9)	375 (33.8)	
with children <12 yr old	535 (14.9)	383 (15.5)	152 (13.7)	
with children >12 yr old	602 (16.8)	368 (14.9)	234 (2112)	
other	597 (16.6)	402 (16.2)	195 (17.6)	
City, n (%)				<.001
Barcelona	979 (27.3)	790 (31.9)	189 (17.1)	
Doetinchem	851 (23.7)	668 (27.0)	183 (16.5)	
Kaunas	892 (24.9)	436 (17.6)	456 (41.1)	
Stoke-on-Trent	864 (24.1)	584 (23.6)	280 (25.3)	
Education, n (%)				.511
low	251 (7.0)	163 (6.6)	88 (7.9)	
medium	1568 (43.7)	1087 (43.9)	481 (43.5)	
high	1767 (49.3)	1228 (49.6)	539 (48.6)	
Perceived income situation, n (%)				<.001
cannot make ends meet	385 (10.7)	276 (11.1)	109 (9.8)	
enough to get by	1800 (50.2)	1165 (47.0)	635 (57.3)	
comfortable	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

detached	888 (24.8)	630 (25.4)	258 (23.3)	
semi-detached	1064 (29.7)	656 (26.5)	408 (36.8)	
flat	1548 (43.2)	1137 (45.9)	411 (37.1)	
other	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
Excellent, (very) good	2662 (74.2)	1939 (78.3)	723 (65.2)	
(Very) Bad	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
healthy weight	1610 (44.9)	1165 (47.0)	445 (40.2)	
overweight	1192 (33.2)	819 (33.1)	373 (33.6)	
obese	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
current	733 (20.5)	478 (19.3)	255 (23.0)	
former	1008 (28.1)	724 (29.2)	284 (25.6)	
never	1843 (51.4)	1275 (51.5)	568 (51.3)	
Frequency of contact with family and/or friends, n (%)				.256
(almost) daily	2135 (59.5)	1470 (59.3)	665 (60.0)	
≥1 per week	1114 (31.1)	781 (31.1)	333 (30.0)	
1-3 per month or less	392 (9.4)	227 (9.2)	111 (10.0)	
Feeling part of a group of friends, n %				<.001
(totally) agree	2414 (67.5)	1754 (70.9)	660 (59.7)	
neutral, (totally) disagree	1165 (32.5)	719 (29.1)	446 (40.3)	

Perceived safety of NOE in NBH, n (%)				.012
(very) satisfied	2123 (59.2)	1486 (60.0)	637 (57.5)	
neutral	776 (21.6)	542 (21.9)	234 (21.1)	
(very) dissatisfied	687 (19.2)	450 (18.2)	237 (21.4)	
NBH SES, n (%)				.425
low	1131 (31.5)	791 (31.9)	340 (30.7)	
medium	1379 (38.4)	938 (37.9)	441 (39.8)	
high	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)
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

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.*

**for analyses with total sample. Analyses were based on complete cases.*

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)
Number of NOE	300m	$p_{interaction}$ .007	$p_{interaction}$ .101	$p_{interaction}$ .700	$p_{interaction}$ .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	$p_{interaction}$ .006	$p_{interaction}$ .015	$p_{interaction}$ .504	$p_{interaction}$ .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	$p_{interaction}$ <.001	$p_{interaction}$ <.001	$p_{interaction}$ .714	$p_{interaction}$ <.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) n=1766	5.63) n=1757		4.32) n=1765
Area of NOE	300m	$p_{interaction}$ .407	$p_{interaction}$ .224	$p_{interaction}$ .286	$p_{interaction}$ .464
	lowest	NA	NA	NA	NA
	highest	NA	NA	NA	NA
	500m	$p_{interaction}$ .071	$p_{interaction}$ .715	$p_{interaction}$ .897	$p_{interaction}$ .693
	lowest	NA	NA	NA	NA
	highest	NA	NA	NA	NA
	1000m	$p_{interaction}$ .114	$p_{interaction}$ .155	$p_{interaction}$ .607	$p_{interaction}$ .019
	lowest	NA	NA	NA	-0.75 (-2.42, 0.92) n=1787
	highest	NA	NA	NA	1.33 (-0.20, 2.85) n=1797
Surrounding greenness (NDVI)	100m	$p_{interaction}$ .820	$p_{interaction}$ .566	$p_{interaction}$ .989	$p_{interaction}$ .142
	lowest	NA	NA	NA	NA
	highest	NA	NA	NA	NA
	300m	$p_{interaction}$ .284	$p_{interaction}$ .895	$p_{interaction}$ .770	$p_{interaction}$ .011
	lowest	NA	NA	NA	1.79 (0.06, 3.52) n=1786
	highest	NA	NA	NA	-0.93 (-2.41, 0.56) n=1798
	500m	$p_{interaction}$ .014	$p_{interaction}$ .248	$p_{interaction}$ .735	$p_{interaction}$ .317
	lowest	1.72 (1.34; 2.22) n=1765	NA	NA	NA
	highest	2.50 (2.03;	NA	NA	NA

		3.09) n=1821			
Distance to nearest NOE		$p_{interaction}$ .043	$p_{interaction}$ .070	$p_{interaction}$ 0.520	$p_{interaction}$ .725
	closest	2.57 (2.04; 3.23) n=1801	NA	NA	NA
	furthest	1.84 (1.48; 2.29) n=1785	NA	NA	NA
Time spent in NOE near home		$p_{interaction}$ .401	NA	$p_{interaction}$ .493	$p_{interaction}$ .150
	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*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—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*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of	10-11

		cases and controls was addressed *Cross-sectional study*—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) *Cohort study*—Summarise follow-up time (eg, average and total amount)	n.a.
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	n.a.
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	n.a.
		Cross-sectional study—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

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

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

BMJ Open

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

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023000.R1
Article Type:	Research
Date Submitted by the Author:	01-Nov-2018
Complete List of Authors:	Zijlema, Wilma; Instituto de Salud Global Barcelona, Christian, Hayley; The University of Western Australia, School of Population Health Triguero-Mas, Margarita; Instituto de Salud Global Barcelona Cirach, Marta; Instituto de Salud Global Barcelona van den Berg, Magdalena; EMGO Institute for Health and Care Research, VU University Medical Center Maas, Jolanda; Vrije Universiteit Amsterdam, Department of Clinical Psychology Gidlow, Christopher; Staffordshire University, Centre for Sport, Health and Exercise Research Kruize, Hanneke; National Institute for Public Health and the Environment,, Centre of Environmental Health Research Wendel-Vos, Wanda; National Institute for Public Health and the Environment, Andrušaitytė, Sandra; 7. Department of Environmental Sciences, Vytautas Magnus University, Kaunas, Lithuania Grazuleviciene, Regina; Vytauto Didziojo Universitetas, Department of Environmental Sciences Litt, Jill; University of Colorado Boulder, Environmental Studies Program Nieuwenhuijsen, Mark; Instituto de Salud Global de Barcelona (ISGlobal), Centre for International Health Research (CRESIB); Instituto de Salud Global de Barcelona (ISGlobal), Centre for Research in Environmental Epidemiology (CREAL)
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Public health
Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, MENTAL HEALTH

Title

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 (incidence rate ratio 1.65, 95% CI 1.65, 1.66 and 1.48, 95% CI 1.45, 1.51 respectively). These

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

Conclusions

Compared with non-dog owners, dog owners walked more and spent more time in NOE, especially in those with access to NOE and in greener areas. The health implications of these relationships should be further investigated. In a largely physically inactive society, dog walking in NOE may be a simple way of promoting physical activity and health.

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

Competing interests

None declared

Funding

This work was supported by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 282996. W.L. Zijlema is supported by a Sara Borrell grant from the Instituto de Salud Carlos III (CD17/00195). H. Christian is supported by an Australian National Heart Foundation Future Leader Fellowship (#100794). ISGlobal is a member of the CERCA Programme, Generalitat de Catalunya. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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.

Acknowledgements

The authors thank Sandra Márquez for her valuable advice in the statistical analyses and the PHENOTYPE respondents for their contribution.

Data sharing statement

Additional data are available upon request from the corresponding author (WLZ: Wilma.zijlema@isglobal.org).

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.

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

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) [39]. Neighborhoods were selected to maximize variability in access to NOE and socioeconomic status. In order to arrive at a final sample of approximately 1000 respondents per city, a random sample of 30 to 35 addresses per neighborhood were mailed with a letter explaining the purpose of the project after which they were visited by interviewers. In Doetinchem, persons were asked to send back an answer card to indicate their willingness to participate before they were visited by the interviewers; and in Kaunas, persons were approached by mail to fill out postal questionnaires. Respondents needed to have an age between 18 and 75 years and to be able to speak the local language. 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.

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.

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. 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 [40] 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 [41], 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 [42]. 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 [43].

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 [40,44]. 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 [44]. 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 values were calculated within (Euclidean) buffers of 100m, 300m, and 500m around the residence, as used in previous research [45,46], and dichotomized using the city-specific median value.

(Figure 1 here)

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

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

Mental health was assessed using the Short Form Health Survey (SF-36) mental health subscale, including five items (e.g. nervousness, depression), and is a valid and reliable measure of mental health [52]. 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 [49] 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.

Covariates and other variables

Information about sociodemographic factors included sex, age, educational level (primary school or no education; secondary school/ further education (up to 18 years); university degree or higher), household composition (alone; with partner (without children); with children <12 yr old; with children >12 yr old; and other), perceived income situation (cannot make ends meet; enough to get by; comfortable), frequency of contact with family and/or friends ((almost daily; ≥1 per week; 1-3 per month or less), and whether respondents feel part of a group of friends ((totally) agree; neutral, (totally) disagree). We also included perceived safety of neighborhood NOE (very satisfied; satisfied; neutral; dissatisfied; very dissatisfied). Health-related factors included disability restricting mobility (yes; no), one or more chronic diseases (yes; no), body mass index (based on self reported height and weight: healthy weight ≤25 kg/m^2; overweight 25-30 kg/m^2; obese >30 kg/m^2), and smoking status (current; former; never). Neighborhood socioeconomic status (SES, low; intermediate; high) was based on country-specific data (Barcelona: deprivation index based on census data 2001 [53]; Doetinchem: average monthly household income per 6-digit zip code level [54]; Kaunas: neighborhood education level [55]; Stoke-on-Trent: English indices of deprivation 2010 [56]).

Statistical analyses

Equivalence tests with Benjamini-Hochberg adjustments for false discovery rates (5%) [57] were used to test for differences between dog owner and non-dog owner characteristics. To investigate 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 good/poor access to NOE and high/low residential surrounding greenness, we investigated:

1. The associations between dog ownership, leisure time walking, time spent in NOE, general health status, and mental health.
2. The associations specified at 1, stratified by NOE access (good and poor) and by residential surrounding greenness (high and low) to investigate whether the associations between dog ownership and the outcomes differ in these subgroups.

Associations were estimated using multilevel analysis with a random intercept defined at the neighborhood level. Associations with leisure time walking and time spent in NOE were estimated with Poisson regression which is used to model count variables; associations with general health status were estimated with logistic regression because of the dichotomous nature of the data; and since mental health scores were normally distributed, associations were estimated with linear regression. Models were adjusted for age, sex, education level, household composition, perceived income situation, neighborhood SES, NOE safety, disability restricting mobility, and chronic diseases and were selected because of an assumed relation with dog ownership, walking, time spent in NOE and health. The main associations (as specified at 1) were also estimated for the cities separately. Stratified analyses by access to NOE and residential surrounding greenness were undertaken with indicators in all buffer sizes, but the 500m buffer was reported in the main table and the remaining buffer sizes in the Supplement. Analyses were based on complete cases (missing data differed by outcome and ranged between n=360 and 416). All analyses were performed in STATA 14.2 [58].

Sensitivity analyses were undertaken to investigate whether additional adjustment for covariates changed the associations. Additional adjustments were carried out for characteristics that were found to differ between dog owners and non-dog owners and that may relate to health (smoking and BMI), or that have been found to be mediators of the dog ownership-health relationship (frequency of contact with family and/or friends, and whether respondents feel part of a group of friends) [59,60].

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

consistently for larger areas of NOE. Stronger associations between dog ownership and walking were predominantly observed for the access to NOE and surrounding greenness indicators in larger buffer sizes (Table 3 and Supplemental Table S2).

The association between dog ownership and time spent in NOE by the number of NOE was also stronger for those with a higher number of NOE (IRR 1.51, 95% CI 1.46, 1.56) compared to those with a lower number of NOE (IRR 1.43, 95% CI 1.39, 1.47). We also observed stronger associations between dog ownership and time spent in NOE for those with larger areas of NOE, for those living within 300m of a NOE and for those with a higher amount of residential surrounding greenness (Table 3 and Supplemental Table S2). The stronger associations between dog ownership and time spent in NOE for those with better access to NOE and with more residential surrounding greenness were consistent across all buffer sizes except for residential surrounding greenness within 100m (Supplemental Table S2).

There were no associations between dog ownership and perceived general health status when stratifying by access to NOE or residential surrounding greenness. Similarly, there was no indication for an association between dog ownership and mental health in groups with high or low access to NOE and with high or low residential surrounding greenness (Table 3).

(Table 3 here)

Sensitivity analysis

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

DISCUSSION

Having a dog was associated with more leisure time walking and time spent in NOE near home compared with not having a dog. Moreover, the differences in walking and time spent in NOE between dog owners and non-dog owners were larger when there was good access to NOE and a high amount of residential surrounding greenness. There was no consistent evidence for an association between dog ownership and perceived general and mental health status. Only dog owners from Stoke-on-Trent had better mental

health compared with non-dog owners, and dog owners from Barcelona had better perceived general health compared to non-dog owners.

Prior studies have also observed links between NOE, dog ownership and physical activity. In support of our findings, a UK study of older adults reported that neighborhood greenness was associated with a smaller decline in physical activity over time, and that dog walking explained up to 50% of the variance in the relationship between greenness and outdoor physical activity [61]. Our findings were also consistent with a Danish study that found that dog ownership was a major determinant of park visits, especially those parks closest to the residence [33]. Our study adds to the evidence base by including multiple exposure indicators of NOE which enabled studying multiple exposure indicators of NOE simultaneously, and could help understand what metric best predicts the health benefits associated with NOE [34,35,39]. We found that dog owners spent more time in NOE than non-dog owners, but dog ownership was not consistently related to perceived mental or general health status. Dog ownership was only related to better perceived general or mental health in Barcelona and Stoke-on-Trent, the two cities where respondents were the least active and spent the least time in NOE. This suggests that the health benefits of dog ownership exist when walking and time spent in NOE is low to begin with. Because we found no consistent evidence for health benefits for dog owners with better availability of NOE, future studies could also investigate subjective indicators of NOE, including satisfaction and importance, and neighborhood aesthetics [62].

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

Limitations of this study include the lack of information about the dog (e.g. breed, age, temperament), the dog owner's level of attachment to their dog, the duration of dog ownership, and if the respondent was the primary carer of the dog. Such factors may have influenced the potential health benefits of dog ownership, but we were unable to take these factors into account. We further did not know if the time spent in NOE and leisure time walking was undertaken together with the dog, and whether time spent in NOE was time spent walking. Future research should measure specific aspects of dog ownership and should use measures of behavior such as time spent in NOE with and without dog and leisure time walking undertaken with and without the dog. A limitation of self-reporting walking habits is potential overstatement of the amount of walking. Although data collection was similar in each city, data on neighborhood SES was based on country-specific data and this might have complicated comparisons between cities. Finally, we cannot establish the direction of the observed relationships because of the cross-sectional study design. For example, people who are already physically active and visit NOE may decide to get a dog, instead of dogs motivating their owners to walk and visit NOE more. Strengths include the multi-city approach, which revealed differences between cities concerning dog ownership and health. It is also one of the first studies from mainland Europe, since the majority of research has been carried out in North America, Australia, and in the UK. More international studies about dog ownership and health are needed. Finally, our measure of access to NOE was specific to environments that were suitable for physical activity. Also, for access to NOE, we used road network buffers over circular buffers which better capture people's walking behavior; and we used varying buffer sizes to obtain a better understanding of what distance to NOE is most beneficial to health [42].

Conclusions

Dog owners performed more leisure time walking and spent more time in NOE compared with non-dog owners, especially when they had access to NOE and when they lived in green areas. There was no consistent relationship between dog ownership and better perceived 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. Cities should therefore ensure that there is access to NOE for dog owners and provide green infrastructure in order to promote dog walking. Future research should focus on natural experiments and evaluation of intervention 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
alone	614 (17.1)	461 (18.6)	153 (13.8)	
with partner (without children)	1239 (34.5)	864 (34.9)	375 (33.8)	
with children <12 yr old	535 (14.9)	383 (15.5)	152 (13.7)	
with children >12 yr old	602 (16.8)	368 (14.9)	234 (2112)	
other	597 (16.6)	402 (16.2)	195 (17.6)	
City, n (%)				<.05
Barcelona	979 (27.3)	790 (31.9)	189 (17.1)	
Doetinchem	851 (23.7)	668 (27.0)	183 (16.5)	
Kaunas	892 (24.9)	436 (17.6)	456 (41.1)	
Stoke-on-Trent	864 (24.1)	584 (23.6)	280 (25.3)	
Education, n (%)				>.05
low	251 (7.0)	163 (6.6)	88 (7.9)	
medium	1568 (43.7)	1087 (43.9)	481 (43.5)	
high	1767 (49.3)	1228 (49.6)	539 (48.6)	
Perceived income situation, n (%)				<.05
cannot make ends meet	385 (10.7)	276 (11.1)	109 (9.8)	
enough to get by	1800 (50.2)	1165 (47.0)	635 (57.3)	
comfortable	1401 (39.1)	1037 (41.9)	364 (32.9)	
Weight status (BMI categories), n (%)				<.05
healthy weight	1610 (44.9)	1165 (47.0)	445 (40.2)	
overweight	1192 (33.2)	819 (33.1)	373 (33.6)	
obese	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
current	733 (20.5)	478 (19.3)	255 (23.0)	
former	1008 (28.1)	724 (29.2)	284 (25.6)	
never	1843 (51.4)	1275 (51.5)	568 (51.3)	
Frequency of contact with family and/or friends, n (%)				>.05
(almost) daily	2135 (59.5)	1470 (59.3)	665 (60.0)	
≥1 per week	1114 (31.1)	781 (31.1)	333 (30.0)	
1-3 per month or less	392 (9.4)	227 (9.2)	111 (10.0)	
Feeling part of a group of friends, n %				<.05
(totally) agree	2414 (67.5)	1754 (70.9)	660 (59.7)	
neutral, (totally) disagree	1165 (32.5)	719 (29.1)	446 (40.3)	
Perceived safety of NOE in NBH, n (%)				<.05
(very) satisfied	2123 (59.2)	1486 (60.0)	637 (57.5)	
neutral	776 (21.6)	542 (21.9)	234 (21.1)	
(very) dissatisfied	687 (19.2)	450 (18.2)	237 (21.4)	
NBH SES, n (%)				>.05
low	1131 (31.5)	791 (31.9)	340 (30.7)	

medium	1379 (38.4)	938 (37.9)	441 (39.8)	
high	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
Excellent, (very) good	2662 (74.2)	1939 (78.3)	723 (65.2)	
(Very) Bad	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.

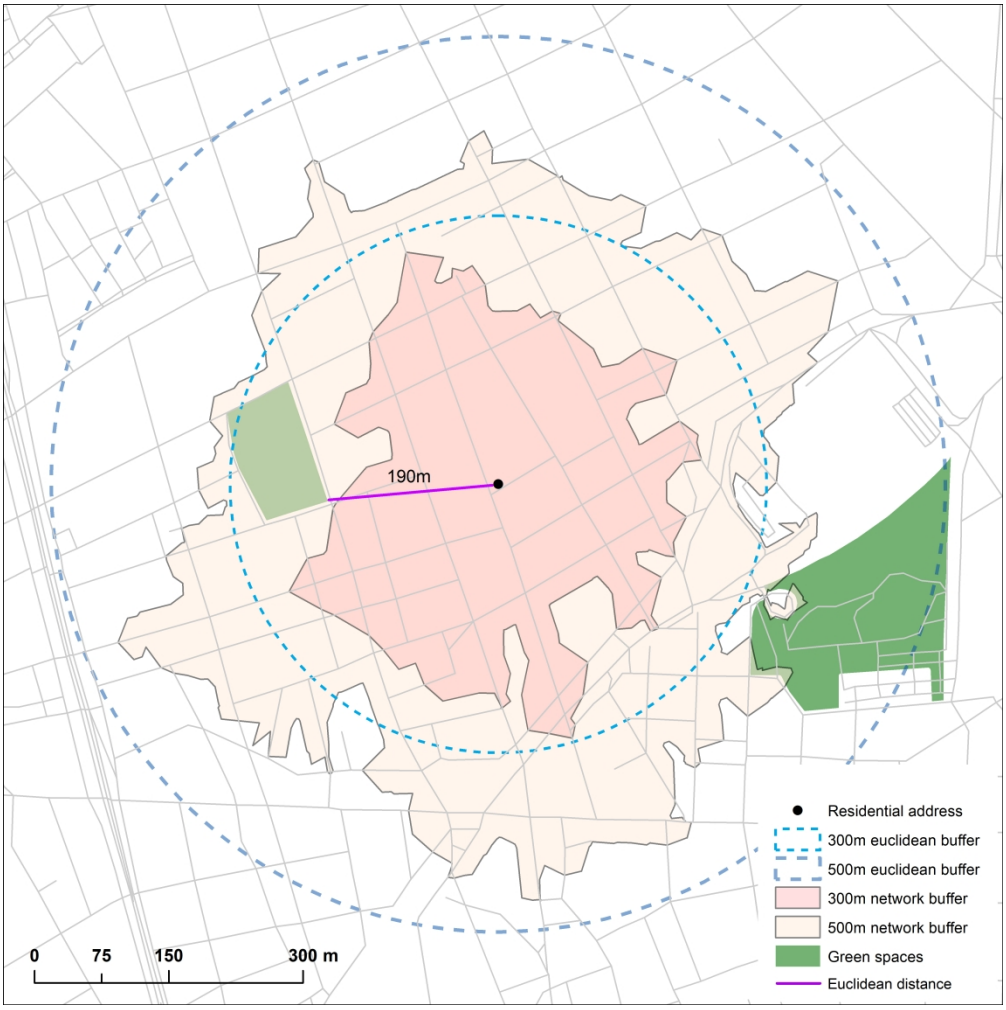

Figure 1. Example of different buffer types and the distance to natural outdoor environments from a residential address.

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)				
with partner (without children)	0.97 (0.96; 0.97)	1.10 (1.07; 1.13)	1.01 (0.75; 1.37)	1.36 (-0.13; 2.85)
with children <12 yr old	0.90 (0.89; 0.91)	1.29 (1.24; 1.33)	0.88 (0.57; 1.36)	2.86 (0.95; 4.76)
with children >12 yr old	0.94 (0 93; 0.94)	1.17 (1.13; 1.21)	1.00 (0.70; 1.45)	1.77 (0.05; 3.49)
other	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)				
medium	0.96 (0.81; 1.13)	1.33 (1.27; 1.40)	0.99 (0.65; 1.49)	3.70 (1.55; 5.84)
high	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)				
enough to get by	0.99 (0.98; 1.00)	0.98 (0.94; 1.01)	1.67 (1.19; 2.35)	2.92 (1.22; 4.63)
comfortable	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)				
satisfied	1.05 (1.04; 1.06)	0.90 (0.87; 0.93)	1.01 (0.66; 1.56)	-2.47 (-4.33; -0.61)
neutral	0.96 (0.95; 0.97)	0.85 (0.81; 0.88)	0.72 (0.46; 1.15)	-4.65 (-6.70; -2.61)
dissatisfied	1.09 (1.08; 1.10)	0.85 (0.82; 0.89)	0.61 (0.38; 0.97)	-5.45 (-7.62; -3.28)
very dissatisfied	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)				
medium	0.96 (0.81; 1.13)	1.02 (0.79; 1.30)	0.92 (0.45; 1.88)	-0.49 (-2.63; 1.64)
high	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

		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	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*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—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*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of	10-11

		cases and controls was addressed *Cross-sectional study*—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) *Cohort study*—Summarise follow-up time (eg, average and total amount)	n.a.
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	n.a.
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	n.a.
		Cross-sectional study—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

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

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

BMJ Open

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

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023000.R2
Article Type:	Research
Date Submitted by the Author:	15-Jan-2019
Complete List of Authors:	Zijlema, Wilma; Instituto de Salud Global Barcelona, Christian, Hayley; The University of Western Australia, School of Population Health Triguero-Mas, Margarita; Instituto de Salud Global Barcelona Cirach, Marta; Instituto de Salud Global Barcelona van den Berg, Magdalena; EMGO Institute for Health and Care Research, VU University Medical Center Maas, Jolanda; Vrije Universiteit Amsterdam, Department of Clinical Psychology Gidlow, Christopher; Staffordshire University, Centre for Sport, Health and Exercise Research Kruize, Hanneke; National Institute for Public Health and the Environment,, Centre of Environmental Health Research Wendel-Vos, Wanda; National Institute for Public Health and the Environment, Andrušaitytė, Sandra; 7. Department of Environmental Sciences, Vytautas Magnus University, Kaunas, Lithuania Grazuleviciene, Regina; Vytauto Didziojo Universitetas, Department of Environmental Sciences Litt, Jill; University of Colorado Boulder, Environmental Studies Program Nieuwenhuijsen, Mark; Instituto de Salud Global de Barcelona (ISGlobal), Centre for International Health Research (CRESIB); Instituto de Salud Global de Barcelona (ISGlobal), Centre for Research in Environmental Epidemiology (CREAL)
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Public health
Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, MENTAL HEALTH

Title

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

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

Conclusions

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

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

Competing interests

None declared

Funding

This work was supported by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 282996. W.L. Zijlema is supported by a Sara Borrell grant from the Instituto de Salud Carlos III (CD17/00195). H. Christian is supported by an Australian National Heart Foundation Future Leader Fellowship (#100794). ISGlobal is a member of the CERCA Programme, Generalitat de Catalunya. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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.

Acknowledgements

The authors thank Sandra Márquez and Xavier Basagaña for their valuable advice in the statistical analyses and the PHENOTYPE respondents for their contribution.

Data sharing statement

Additional data are available upon request from the corresponding author (WLZ: Wilma.zijlema@isglobal.org).

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

factors that influence health outcomes (e.g. access to NOE) could lead to potential intervention strategies that could eventually improve health.

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

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) [41,42]. Neighborhoods were selected to maximize variability in access to NOE and socioeconomic status. In order to arrive at a final sample of approximately 1000 respondents per city, a random sample of 30 to 35 addresses per neighborhood were mailed with a letter explaining the purpose of the project after which they were visited by interviewers. In Doetinchem, persons were asked to send back an answer card to indicate their willingness to participate before they were visited by the interviewers; and in Kaunas, persons were approached by mail to fill out postal questionnaires. Respondents needed to have an age between 18 and 75 years and to be able to speak the local language. 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 (Parc de Salut Mar, Clinical Research Ethics Committee reference number 2011/4206/I; Medisch Ethische Toestingscommissie UMCU reference number 12/595; Lietuvos Bioetikos Komitetas reference number 6B-12-147; Faculty of Health 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

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

(Figure 1 here)

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

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) [49]. The SQUASH is a valid measure of physical activity [49,50]. 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

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). 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) [51]. 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 [52,53].

Mental health

Mental health was assessed using the Short Form Health Survey (SF-36) mental health subscale, including five items (e.g. nervousness, depression), and is a valid and reliable measure of mental health [54]. 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 [51] 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.

Covariates and other variables

Information about sociodemographic factors included sex, age, educational level (primary school or no education; secondary school/ further education (up to 18 years); university degree or higher), household composition (alone; with partner (without children); with children <12 yr old; with children >12 yr old; and other), perceived income situation (cannot make ends meet; enough to get by; comfortable), frequency of contact with family and/or friends ((almost daily; ≥1 per week; 1-3 per month or less), and whether respondents feel part of a group of friends ((totally) agree; neutral, (totally) disagree). We also included perceived safety of neighborhood NOE (very satisfied; satisfied; neutral; dissatisfied; very dissatisfied). Health-related factors included disability restricting mobility (yes; no), one or more chronic diseases (yes; no), body mass index (based on self reported height and weight: healthy weight ≤25 kg/m^2; overweight 25-30 kg/m^2; obese >30 kg/m^2), and smoking status (current; former; never). Neighborhood socioeconomic

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

Statistical analyses

Equivalence tests with Benjamini-Hochberg adjustments for false discovery rates (5%) [59] were used to test for differences between dog owner and non-dog owner characteristics. To investigate the association between dog ownership, and outcomes leisure time walking, time spent in NOE, and general and mental health status, and whether these associations differed for respondents with good/poor access to NOE and high/low residential surrounding greenness, we investigated:

1. The associations between dog ownership, and outcomes leisure time walking, time spent in NOE, general health status, and mental health.
2. The associations specified at 1, stratified by NOE access (good and poor) and by residential surrounding greenness (high and low) to investigate whether the associations between dog ownership and the outcomes differ in these subgroups.

Associations were estimated using multilevel analysis with a random intercept defined at the neighborhood level. Associations with leisure time walking, time spent in NOE and general health status were estimated with logistic regression because of the dichotomization of the data; and since mental health scores were normally distributed, associations were estimated with linear regression. Models were adjusted for age, sex, education level, household composition, perceived income situation, neighborhood SES, NOE safety, disability restricting mobility, and chronic diseases and were selected because of an assumed relation with dog ownership, walking, time spent in NOE and health. The main associations (as specified at 1) were also estimated for the cities separately. Stratified analyses by access to NOE and residential surrounding greenness were undertaken with indicators in all buffer sizes, but the 500m buffer was reported in the main table and the remaining buffer sizes in the Supplement. Analyses were based on complete cases (missing data differed by outcome and ranged between n=360 and 416). All analyses were performed in STATA 14.2 [60].

Sensitivity analyses were undertaken to investigate whether additional adjustment for covariates changed the associations. Additional adjustments were carried out for characteristics that were found to differ between dog owners and non-dog owners and that may relate to health (smoking and BMI), or that have been found to be mediators of the dog ownership-health relationship (frequency of contact with family and/or friends, and whether respondents feel part of a group of friends) [61,62].

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

those with a high amount of residential surrounding greenness (100 and 300m buffer, Supplemental Table S2) compared to low residential surrounding greenness.

The associations between dog ownership and time spent in NOE were larger for those with a lower number or area of NOE than for those with a higher number or area of NOE (Table 3 and Supplemental Table S2). We observed stronger associations between dog ownership and time spent in NOE for those living within 300m of a NOE (OR= 2.64, 95% CI 2.18, 3.20) compared to those living within >300m of a NOE (OR= 1.82, 95% CI 1.31, 2.55; Table 3). Stronger associations between dog ownership and time spent in NOE for those with more residential surrounding greenness were consistent across buffer sizes 300m and 500m, but not for residential surrounding greenness within 100m (Table 3 and Supplemental Table S2).

There were no associations between dog ownership and perceived general health status when stratifying by access to NOE or residential surrounding greenness. Similarly, there was no indication for an association between dog ownership and mental health in groups with high or low access to NOE and with high or low residential surrounding greenness (Table 3).

(Table 3 here)

Sensitivity analysis

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

DISCUSSION

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

Prior studies have also observed links between NOE, dog ownership and physical activity. In support of our findings, a UK study of older adults reported that neighborhood greenness was associated with a smaller decline in physical activity over time, and that dog walking explained up to 50% of the variance in the relationship between greenness and outdoor physical activity [63]. Our findings were also consistent with a Danish study that found that dog ownership was a major determinant of park visits, especially those parks closest to the residence [35]. Our study adds to the evidence base by including multiple exposure indicators of NOE which enabled studying multiple exposure indicators of NOE simultaneously, and could help understand what metric best predicts the health benefits associated with NOE [36,37,41]. We found that dog owners spent more time in NOE than non-dog owners, but dog ownership was not consistently related to perceived mental or general health status. Dog ownership was only related to better perceived general or mental health in Barcelona and Stoke-on-Trent, the two cities where respondents were the least active and spent the least time in NOE. This suggests that the health benefits of dog ownership exist when walking and time spent in NOE is low to begin with. Because we found no consistent evidence for health benefits for dog owners with better availability of NOE, future studies could also investigate subjective indicators of NOE, including satisfaction and importance, and neighborhood aesthetics [64].

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

Limitations of this study include the lack of information about the dog (e.g. breed, age, temperament), the dog owner's level of attachment to their dog, the duration of dog ownership, and if the respondent was the primary carer of the dog. Such factors may have influenced the potential health benefits of dog ownership, but we were unable to take these factors into account. We further did not know if the time spent in NOE

and leisure time walking was undertaken together with the dog, and whether time spent in NOE was time spent walking. Future research should measure specific aspects of dog ownership and should use measures of behavior such as time spent in NOE with and without dog and leisure time walking undertaken with and without the dog. A limitation of self-reporting walking habits is potential overstatement of the amount of walking. Minutes of walking and time in NOE were dichotomized because of non-normal distributions and although this resulted in easier interpretation of data, it also resulted in information loss. Although data collection was similar in each city, data on neighborhood SES was based on country-specific data and this might have complicated comparisons between cities. Finally, we cannot establish the direction of the observed relationships because of the cross-sectional study design. For example, people who are already physically active and visit NOE may decide to get a dog, instead of dogs motivating their owners to walk and visit NOE more. Strengths include the multi-city approach, which revealed differences between cities concerning dog ownership and health. It is also one of the first studies from mainland Europe, since the majority of research has been carried out in North America, Australia, and in the UK. More international studies about dog ownership and health are needed. Finally, our measure of access to NOE was specific to environments that were suitable for physical activity. Also, for access to NOE, we used road network buffers over circular buffers which better capture people's walking behavior; and we used varying buffer sizes to obtain a better understanding of what distance to NOE is most beneficial to health [44].

Conclusions

Dog owners performed more leisure time walking and spent more time in NOE compared with non-dog owners, especially when they lived within 300m of a NOE and when they lived in green areas. There was no consistent relationship between dog ownership and better perceived 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. Cities should therefore ensure that there is access to NOE for dog owners and provide green infrastructure in order to promote dog walking. Future research should focus on natural experiments and evaluation of intervention 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
alone	614 (17.1)	461 (18.6)	153 (13.8)	
with partner (without children)	1239 (34.5)	864 (34.9)	375 (33.8)	
with children <12 yr old	535 (14.9)	383 (15.5)	152 (13.7)	
with children >12 yr old	602 (16.8)	368 (14.9)	234 (2112)	
other	597 (16.6)	402 (16.2)	195 (17.6)	
City, n (%)				<.05
Barcelona	979 (27.3)	790 (31.9)	189 (17.1)	
Doetinchem	851 (23.7)	668 (27.0)	183 (16.5)	
Kaunas	892 (24.9)	436 (17.6)	456 (41.1)	
Stoke-on-Trent	864 (24.1)	584 (23.6)	280 (25.3)	
Education, n (%)				>.05
low	251 (7.0)	163 (6.6)	88 (7.9)	
medium	1568 (43.7)	1087 (43.9)	481 (43.5)	
high	1767 (49.3)	1228 (49.6)	539 (48.6)	
Perceived income situation, n (%)				<.05
cannot make ends meet	385 (10.7)	276 (11.1)	109 (9.8)	
enough to get by	1800 (50.2)	1165 (47.0)	635 (57.3)	
comfortable	1401 (39.1)	1037 (41.9)	364 (32.9)	
Weight status (BMI categories), n (%)				<.05
healthy weight	1610 (44.9)	1165 (47.0)	445 (40.2)	
overweight	1192 (33.2)	819 (33.1)	373 (33.6)	
obese	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
current	733 (20.5)	478 (19.3)	255 (23.0)	
former	1008 (28.1)	724 (29.2)	284 (25.6)	
never	1843 (51.4)	1275 (51.5)	568 (51.3)	
Frequency of contact with family and/or friends, n (%)				>.05
(almost) daily	2135 (59.5)	1470 (59.3)	665 (60.0)	
≥1 per week	1114 (31.1)	781 (31.1)	333 (30.0)	
1-3 per month or less	392 (9.4)	227 (9.2)	111 (10.0)	
Feeling part of a group of friends, n %				<.05
(totally) agree	2414 (67.5)	1754 (70.9)	660 (59.7)	
neutral, (totally) disagree	1165 (32.5)	719 (29.1)	446 (40.3)	
Perceived safety of NOE in NBH, n (%)				<.05
(very) satisfied	2123 (59.2)	1486 (60.0)	637 (57.5)	
neutral	776 (21.6)	542 (21.9)	234 (21.1)	
(very) dissatisfied	687 (19.2)	450 (18.2)	237 (21.4)	
NBH SES, n (%)				>.05
low	1131 (31.5)	791 (31.9)	340 (30.7)	

medium	1379 (38.4)	938 (37.9)	441 (39.8)	
high	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
Excellent, (very) good	2662 (74.2)	1939 (78.3)	723 (65.2)	
(very) Bad	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	≤300m	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
	>300m	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.*

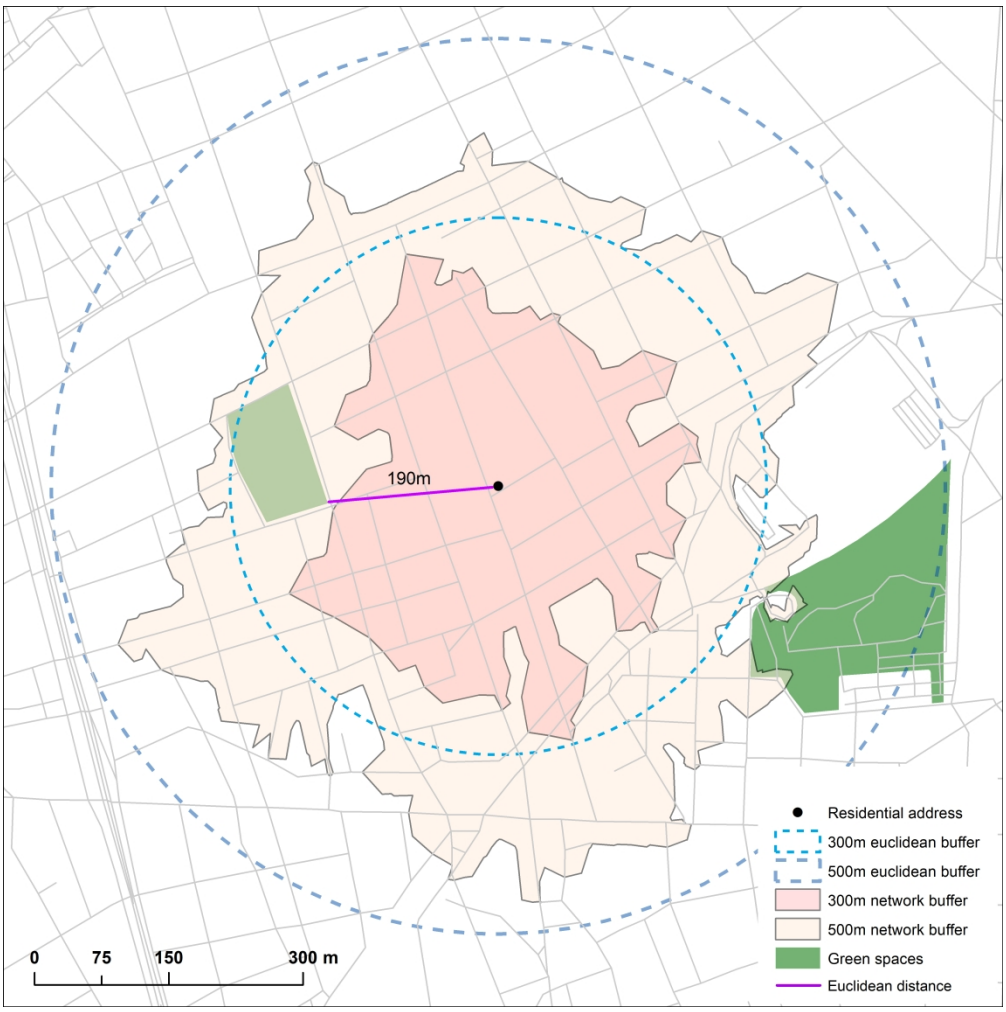

Figure 1. Example of different buffer types and the distance to natural outdoor environments from a residential address.

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)				
with partner (without children)	1.04 (0.84; 1.28)	0.99 (0.80; 1.24)	1.01 (0.75; 1.37)	1.36 (-0.13; 2.85)
with children <12 yr old	0.87 (0.66; 1.14)	1.55 (1.18; 2.05)	0.88 (0.57; 1.36)	2.86 (0.95; 4.76)
with children >12 yr old	0.88 (0.69; 1.13)	1.12 (0.87; 1.44)	1.00 (0.70; 1.45)	1.77 (0.05; 3.49)
other	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)				
medium	1.72 (1.26; 2.36)	1.41 (1.02; 1.95)	0.99 (0.65; 1.49)	3.70 (1.55; 5.84)
high	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)				
enough to get by	0.79 (0.62; 1.00)	1.12 (0.63; 1.08)	1.67 (1.19; 2.35)	2.92 (1.22; 4.63)
comfortable	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)				
satisfied	1.10 (0.85; 1.44)	0.83 (0.63; 1.08)	1.01 (0.66; 1.56)	-2.47 (-4.33; -0.61)
neutral	1.10 (0.83; 1.48)	0.68 (0.51; 0.92)	0.72 (0.46; 1.15)	-4.65 (-6.70; -2.61)
dissatisfied	1.31 (0.97; 1.78)	0.74 (0.54; 1.01)	0.61 (0.38; 0.97)	-5.45 (-7.62; -3.28)
very dissatisfied	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)				
medium	1.08 (0.87; 1.34)	1.05 (0.79; 1.39)	0.92 (0.45; 1.88)	-0.49 (-2.63; 1.64)
high	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

		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	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*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—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*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of	10-11

		cases and controls was addressed *Cross-sectional study*—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) *Cohort study*—Summarise follow-up time (eg, average and total amount)	n.a.
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	n.a.
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	n.a.
		Cross-sectional study—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

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

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

BMJ Open

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

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023000.R3
Article Type:	Research
Date Submitted by the Author:	12-Mar-2019
Complete List of Authors:	Zijlema, Wilma; Instituto de Salud Global Barcelona, Christian, Hayley; The University of Western Australia, School of Population Health Triguero-Mas, Margarita; Instituto de Salud Global Barcelona Cirach, Marta; Instituto de Salud Global Barcelona van den Berg, Magdalena; EMGO Institute for Health and Care Research, VU University Medical Center Maas, Jolanda; Vrije Universiteit Amsterdam, Department of Clinical Psychology Gidlow, Christopher; Staffordshire University, Centre for Sport, Health and Exercise Research Kruize, Hanneke; National Institute for Public Health and the Environment,, Centre of Environmental Health Research Wendel-Vos, Wanda; National Institute for Public Health and the Environment, Andrušaitytė, Sandra; 7. Department of Environmental Sciences, Vytautas Magnus University, Kaunas, Lithuania Grazuleviciene, Regina; Vytauto Didziojo Universitetas, Department of Environmental Sciences Litt, Jill; University of Colorado Boulder, Environmental Studies Program Nieuwenhuijsen, Mark; Instituto de Salud Global de Barcelona (ISGlobal), Centre for International Health Research (CRESIB); Instituto de Salud Global de Barcelona (ISGlobal), Centre for Research in Environmental Epidemiology (CREAL)
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Public health
Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, MENTAL HEALTH

Title

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

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

Conclusions

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

Strengths and limitations of this study

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

Competing interests

None declared

Funding

This work was supported by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 282996. W.L. Zijlema is supported by a Sara Borrell grant from the Instituto de Salud Carlos III (CD17/00195). H. Christian is supported by an Australian National Heart Foundation Future Leader Fellowship (#100794). ISGlobal is a member of the CERCA Programme, Generalitat de Catalunya. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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.

Acknowledgements

The authors thank Sandra Márquez and Xavier Basagaña for their valuable advice in the statistical analyses and the PHENOTYPE respondents for their contribution.

Data sharing statement

Additional data are available upon request from the corresponding author (WLZ: Wilma.zijlema@isglobal.org).

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

factors that influence health outcomes (e.g. access to NOE) could lead to potential intervention strategies that could eventually improve health.

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

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) [41,42]. Neighborhoods were selected to maximize variability in access to NOE and socioeconomic status. In order to arrive at a final sample of approximately 1000 respondents per city, a random sample of 30 to 35 addresses per neighborhood were mailed with a letter explaining the purpose of the project after which they were visited by interviewers. In Doetinchem, persons were asked to send back an answer card to indicate their willingness to participate before they were visited by the interviewers; and in Kaunas, persons were approached by mail to fill out postal questionnaires. Respondents needed to have an age between 18 and 75 years and to be able to speak the local language. 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 (Parc de Salut Mar, Clinical Research Ethics Committee reference number 2011/4206/I; Medisch Ethische Toestingscommissie UMCU reference number 12/595; Lietuvos Bioetikos Komitetas reference number 6B-12-147; Faculty of Health 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

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

(Figure 1 here)

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

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) [49]. The SQUASH is a valid measure of physical activity [49,50]. 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

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). 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) [51]. 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 [52,53].

Mental health

Mental health was assessed using the Short Form Health Survey (SF-36) mental health subscale, including five items (e.g. nervousness, depression), and is a valid and reliable measure of mental health [54]. 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 [51] 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.

Covariates and other variables

Information about sociodemographic factors included sex, age, educational level (primary school or no education; secondary school/ further education (up to 18 years); university degree or higher), household composition (alone; with partner (without children); with children <12 yr old; with children >12 yr old; and other), perceived income situation (cannot make ends meet; enough to get by; comfortable), frequency of contact with family and/or friends ((almost daily; ≥1 per week; 1-3 per month or less), and whether respondents feel part of a group of friends ((totally) agree; neutral, (totally) disagree). We also included perceived safety of neighborhood NOE (very satisfied; satisfied; neutral; dissatisfied; very dissatisfied). Health-related factors included disability restricting mobility (yes; no), one or more chronic diseases (yes; no), body mass index (based on self reported height and weight: healthy weight ≤25 kg/m^2; overweight 25-30 kg/m^2; obese >30 kg/m^2), and smoking status (current; former; never). Neighborhood socioeconomic

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

Statistical analyses

Equivalence tests with Benjamini-Hochberg adjustments for false discovery rates (5%) [59] were used to test for differences between dog owner and non-dog owner characteristics. To investigate the association between dog ownership, and outcomes leisure time walking, time spent in NOE, and general and mental health status, and whether these associations differed for respondents with good/poor access to NOE and high/low residential surrounding greenness, we investigated:

1. The associations between dog ownership, and outcomes leisure time walking, time spent in NOE, general health status, and mental health.
2. The associations specified at 1, stratified by NOE access (good and poor) and by residential surrounding greenness (high and low) to investigate whether the associations between dog ownership and the outcomes differ in these subgroups.

Associations were estimated using multilevel analysis with a random intercept defined at the neighborhood level. Associations with leisure time walking, time spent in NOE and general health status were estimated with logistic regression because of the dichotomization of the data; and since mental health scores were normally distributed, associations were estimated with linear regression. Models were adjusted for age, sex, education level, household composition, perceived income situation, neighborhood SES, NOE safety, disability restricting mobility, and chronic diseases and were selected because of an assumed relation with dog ownership, walking, time spent in NOE and health. The main associations (as specified at 1) were also estimated for the cities separately. Stratified analyses by access to NOE and residential surrounding greenness were undertaken with indicators in all buffer sizes, but the 500m buffer was reported in the main table and the remaining buffer sizes in the Supplement. Analyses were based on complete cases (missing data differed by outcome and ranged between n=360 and 416). All analyses were performed in STATA 14.2 [60].

Sensitivity analyses were undertaken to investigate whether additional adjustment for covariates changed the associations. Additional adjustments were carried out for characteristics that were found to differ between dog owners and non-dog owners and that may relate to health (smoking and BMI), or that have been found to be mediators of the dog ownership-health relationship (frequency of contact with family and/or friends, and whether respondents feel part of a group of friends) [61,62].

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

with a high amount of residential surrounding greenness (100 and 300m buffer, Supplemental Table S2) compared to low residential surrounding greenness.

The associations between dog ownership and time spent in NOE were larger for those with a lower number or area of NOE than for those with a higher number or area of NOE (Table 3 and Supplemental Table S2). We observed a larger odds ratio for the association between dog ownership and time spent in NOE for those living within 300m of a NOE (OR= 2.64, 95% CI 2.18, 3.20) compared to those living within >300m of a NOE (OR= 1.82, 95% CI 1.31, 2.55; Table 3). A larger odds ratio for the association between dog ownership and time spent in NOE for those with more residential surrounding greenness were consistent across buffer sizes 300m and 500m, but not for residential surrounding greenness within 100m (Table 3 and Supplemental Table S2).

There were no statistically significant associations between dog ownership and perceived general health status when stratifying by access to NOE or residential surrounding greenness. Similarly, there was no indication for an association between dog ownership and mental health in groups with high or low access to NOE and with high or low residential surrounding greenness (Table 3).

(Table 3 here)

Sensitivity analysis

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

DISCUSSION

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

mental health compared with non-dog owners, and dog owners from Barcelona had better perceived general health compared to non-dog owners.

Prior studies have also observed links between NOE, dog ownership and physical activity. In support of our findings, a UK study of older adults reported that neighborhood greenness was associated with a smaller decline in physical activity over time, and that dog walking explained up to 50% of the variance in the relationship between greenness and outdoor physical activity [63]. Our findings were also consistent with a Danish study that found that dog ownership was a major determinant of park visits, especially those parks closest to the residence [35]. Our study adds to the evidence base by including multiple exposure indicators of NOE which enabled studying multiple exposure indicators of NOE simultaneously, and could help understand what metric best predicts the health benefits associated with NOE [36,37,41]. We found that dog owners spent more time in NOE than non-dog owners, but dog ownership was not consistently related to perceived mental or general health status. Dog ownership was only related to better perceived general or mental health in Barcelona and Stoke-on-Trent, the two cities where respondents were the least active and spent the least time in NOE. This suggests that the health benefits of dog ownership exist when walking and time spent in NOE is low to begin with. Because we found no consistent evidence for health benefits for dog owners with better availability of NOE, future studies could also investigate subjective indicators of NOE, including satisfaction and importance, and neighborhood aesthetics [64].

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

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

Conclusions

Dog owners performed more leisure time walking and spent more time in NOE compared with non-dog owners, especially when they lived within 300m of a NOE and when they lived in green areas. There was no consistent relationship between dog ownership and better perceived 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. Cities should therefore ensure that there is access to NOE for dog owners and provide green infrastructure in order to promote dog walking. Future research should focus on natural experiments and evaluation of intervention 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
alone	614 (17.1)	461 (18.6)	153 (13.8)	
with partner (without children)	1239 (34.5)	864 (34.9)	375 (33.8)	
with children <12 yr old	535 (14.9)	383 (15.5)	152 (13.7)	
with children >12 yr old	602 (16.8)	368 (14.9)	234 (2112)	
other	597 (16.6)	402 (16.2)	195 (17.6)	
City, n (%)				0.001
Barcelona	979 (27.3)	790 (31.9)	189 (17.1)	
Doetinchem	851 (23.7)	668 (27.0)	183 (16.5)	
Kaunas	892 (24.9)	436 (17.6)	456 (41.1)	
Stoke-on-Trent	864 (24.1)	584 (23.6)	280 (25.3)	
Education, n (%)				0.530
low	251 (7.0)	163 (6.6)	88 (7.9)	
medium	1568 (43.7)	1087 (43.9)	481 (43.5)	
high	1767 (49.3)	1228 (49.6)	539 (48.6)	
Perceived income situation, n (%)				0.001
cannot make ends meet	385 (10.7)	276 (11.1)	109 (9.8)	
enough to get by	1800 (50.2)	1165 (47.0)	635 (57.3)	
comfortable	1401 (39.1)	1037 (41.9)	364 (32.9)	
Weight status (BMI categories), n (%)				0.001
healthy weight	1610 (44.9)	1165 (47.0)	445 (40.2)	
overweight	1192 (33.2)	819 (33.1)	373 (33.6)	
obese	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
current	733 (20.5)	478 (19.3)	255 (23.0)	
former	1008 (28.1)	724 (29.2)	284 (25.6)	
never	1843 (51.4)	1275 (51.5)	568 (51.3)	
Frequency of contact with family and/or friends, n (%)				0.299
(almost) daily	2135 (59.5)	1470 (59.3)	665 (60.0)	
≥1 per week	1114 (31.1)	781 (31.1)	333 (30.0)	
1-3 per month or less	392 (9.4)	227 (9.2)	111 (10.0)	
Feeling part of a group of friends, n %				0.001
(totally) agree	2414 (67.5)	1754 (70.9)	660 (59.7)	
neutral, (totally) disagree	1165 (32.5)	719 (29.1)	446 (40.3)	
Perceived safety of NOE in NBH, n (%)				0.016
(very) satisfied	2123 (59.2)	1486 (60.0)	637 (57.5)	
neutral	776 (21.6)	542 (21.9)	234 (21.1)	
(very) dissatisfied	687 (19.2)	450 (18.2)	237 (21.4)	
NBH SES, n (%)				0.474
low	1131 (31.5)	791 (31.9)	340 (30.7)	
medium	1379 (38.4)	938 (37.9)	441 (39.8)	
high	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
Excellent, (very) good	2662 (74.2)	1939 (78.3)	723 (65.2)	
(very) Bad	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	≤300m	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
	>300m	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.*

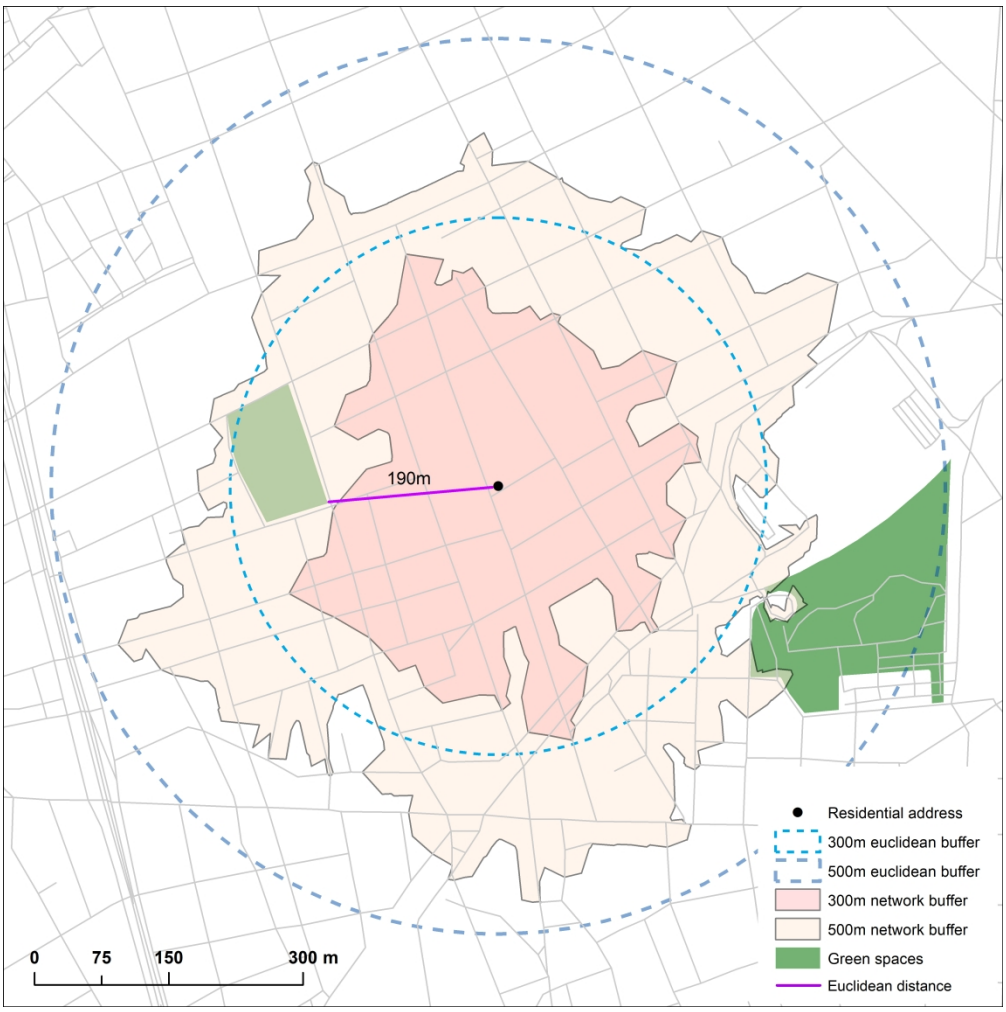

Figure 1. Example of different buffer types and the distance to natural outdoor environments from a residential address.

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)				
with partner (without children)	1.04 (0.84; 1.28)	0.99 (0.80; 1.24)	1.01 (0.75; 1.37)	1.36 (-0.13; 2.85)
with children <12 yr old	0.87 (0.66; 1.14)	1.55 (1.18; 2.05)	0.88 (0.57; 1.36)	2.86 (0.95; 4.76)
with children >12 yr old	0.88 (0.69; 1.13)	1.12 (0.87; 1.44)	1.00 (0.70; 1.45)	1.77 (0.05; 3.49)
other	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)				
medium	1.72 (1.26; 2.36)	1.41 (1.02; 1.95)	0.99 (0.65; 1.49)	3.70 (1.55; 5.84)
high	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)				
enough to get by	0.79 (0.62; 1.00)	1.12 (0.63; 1.08)	1.67 (1.19; 2.35)	2.92 (1.22; 4.63)
comfortable	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)				
satisfied	1.10 (0.85; 1.44)	0.83 (0.63; 1.08)	1.01 (0.66; 1.56)	-2.47 (-4.33; -0.61)
neutral	1.10 (0.83; 1.48)	0.68 (0.51; 0.92)	0.72 (0.46; 1.15)	-4.65 (-6.70; -2.61)
dissatisfied	1.31 (0.97; 1.78)	0.74 (0.54; 1.01)	0.61 (0.38; 0.97)	-5.45 (-7.62; -3.28)
very dissatisfied	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)				
medium	1.08 (0.87; 1.34)	1.05 (0.79; 1.39)	0.92 (0.45; 1.88)	-0.49 (-2.63; 1.64)
high	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

		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	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*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—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*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of	10-11

		cases and controls was addressed *Cross-sectional study*—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) *Cohort study*—Summarise follow-up time (eg, average and total amount)	n.a.
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	n.a.
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	n.a.
		Cross-sectional study—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

*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.