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# Living Environment Matters: Relationships Between Neighborhood Characteristics and Health of the Residents in a Dutch Municipality

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**Abstract** Characteristics of an individual alone cannot exhaustively explain all the causes of poor health, and neighborhood of residence have been suggested to be one of the factors that contribute to health. However, knowledge about aspects of the neighborhood that are most important to health is limited. The main objective of this study was to explore associations between certain features of neighborhood environment and self-rated health and depressive symptoms in Maastricht (The Netherlands). A large amount of routinely collected neighborhood data were aggregated by means of factor analysis to 18 characteristics of neighborhood social and physical environment. Associations between these characteristics and self-rated health and presence of depressive symptoms were further explored in multilevel logistic regression models adjusted for individual demographic and socio-economic factors. The study sample consisted of 9,879 residents (mean age 55 years, 48 % male). Residents of unsafe communities were less likely to report good health (OR 0.88 95 % CI 0.80–0.97) and depressive symptoms (OR 0.81 95 % CI 0.69–0.97), and less cohesive environment was related to worse self-rated health (OR 0.81 95 % CI 0.72–0.92). Residents of neighborhoods with more car traffic nuisance and more disturbance from railway noise reported worse mental health (OR 0.79 95 % CI 0.68–0.92 and 0.85 95 % CI 0.73–0.99, respectively). We did not observe any association between health and quality of parking and shopping facilities, facilities for public or private transport, neighborhood aesthetics, green space, industrial nuisance, sewerage, neighbor nuisance or

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satisfaction with police performance. Our findings can be used to support development of integrated health policies targeting broader determinants of health. Improving safety, social cohesion and decreasing traffic nuisance in disadvantaged neighborhoods might be a promising way to improve the health of residents and reduce health inequalities.

**Keywords** Neighborhood · Social and physical environment · Self-rated health · Depressive symptoms · Socio-economic inequalities

## Introduction

Socio-economic inequalities in health persist despite constant efforts to improve the health of disadvantaged populations and reduce the gap [1]. There is a recognized need for action on the social determinants of health across the life course to achieve greater health equity and protect future generations [2, 3].

Characteristics of an individual alone cannot exhaustively explain all the causes of poor health and do not successfully capture all disease determinants [4]. Place of residence has emerged as a potentially relevant factor representing physical and social attributes that could affect the health of the residents, either directly (e.g. air pollution or dangerous physical environment) or, in many cases, indirectly (e.g. via levels of stress, healthy and unhealthy lifestyles, access to health and social services). Many studies around the world have shown that living in deprived areas is associated with poorer health [5–7]. However, results are often based on a limited number of environment features and/or aggregated deprivation measures, thus hindering the opportunities to make inferences about the relative importance of different neighborhood properties.

Researchers often had to use larger areas (e.g. 4-digit postal codes in the Netherlands, an administrative area within a city with approximately 4,000 residents) as a proxy for neighborhoods, due to data restrictions in large population surveys [8, 9]. So far, only a handful of studies have attempted to provide a comprehensive and detailed picture of the neighborhood environment characteristics [10]. A comprehensive look at neighborhood environments would allow one to find out which aspects of the environment are relatively more important. Distinguishing specific features of the neighborhood environment that are associated with health beyond the individual characteristics is still required to underpin existing community health policies and support the development of new ones. In addition, it has been observed that some features of neighborhoods are differently associated with health in population subgroups (e.g. women or men, younger or older residents) [11]. Evidence is not conclusive and exploring the relationships between different neighborhood features and health in different age, gender or socio-economic groups would provide additional insights.

In recent years, the health status of the population of the Southern Limburg region of the Netherlands has been below the national average, and within the region there are significant socio-economic differences in health status [12–15]. Municipal authorities in Southern Limburg (but also in general in the Netherlands) have a tradition of monitoring physical and social environments to tailor their policy implementation, and therefore have large amounts of routinely collected data available. This makes the region a relevant case to visualize potential neighborhood effects on health.

The objective of the present study was to explore (1) the associations between the social and physical environment of neighborhoods and self-rated health and depressive symptoms in Southern Limburg (The Netherlands) and (2) whether the relationships between the characteristics of the neighborhood environment and health differ depending on gender, age, education or income group.

## Methods

### Source of Data

Cross-sectional survey data from Maastricht, the largest municipality in Southern Limburg, were used. This survey is conducted biannually by the municipal authorities among non-institutionalized inhabitants, and uses a probability sample, obtained by the "next birthday" method. A questionnaire is sent to a household, and the person whose birthday comes earliest after the date on which the questionnaire was received is asked to complete it. The survey included questions on aspects of the neighborhood environment such as quality and accessibility of facilities, safety and nuisance, quality of housing, perceptions of traffic and the built environment, aspects of social capital, health status, demographic and socio-economic background, including age, gender, education and income group. The survey is conducted among adults aged 18 years or over. We used data from 2010.

### Variables

Data on demographics (age and gender), socio-economic status (education and income) and health were extracted. Socio-economic status was measured by level of educational achievement and income group. Six originally asked education categories were classified as low education

(primary education, lower vocational education, pre-vocational secondary education), secondary education (secondary vocational education, senior general secondary education/pre-university education) or higher education (Bachelor and higher). Income group was self-reported by the respondents as low, medium or high, without providing an exact income level in monetary terms. Self-rated health was measured by a question "How would you rate your health in general?" with five answer categories, and we dichotomized it as good (excellent, very good or good) versus poor (fair or poor). Presence of depressive symptoms (high level vs. medium or low level of symptoms of anxiety and depression) was measured by the Kessler Physiological Distress Scale [16] used as a proxy for mental health.

## Statistical Analysis

The first step in the analysis was to create aggregated measures from the environmental variables. To reduce the number of variables of the physical and social neighborhood environment, as a first step, the questionnaire was reviewed by five members of the project group (NKV, MJ, SM, IJK and PP) to identify all questions that were relevant to assessing physical or social environment. Disagreements were resolved until consensus was reached. Second, exploratory factor analyses were conducted. Scale reliability analyses were performed for identified factors to determine the internal consistency between the indicators grouped in each factor (Cronbach's Alpha $>0.7$). Next, each factor was labeled based on face validity upon a consensus among the project group. A total score was computed for each factor. To adjust for different numbers of answering alternatives, each individual component was recoded to a scale of 0–10, where ten corresponded to the most favorable answer (e.g. for the question with five answer categories, the following scores would be assigned: "absolutely not satisfied" $= 0$, "not satisfied" $= 2.5$, "not dissatisfied/not satisfied" $= 5$, "satisfied" $= 7.5$, "very satisfied" $= 10$). The total score for a factor was computed as the mean of the individual components, which also took values from 0 to 10. If one individual component was missing, the mean of the remaining components was taken. If more than one individual component was missing, the total score of the factor was considered to be missing.

In the second step, we constructed multilevel logistic regression models (with individuals clustered in the neighborhoods) to explore the relationship between each computed measure of physical and social environment and each of the two health outcomes. Self-rated health and mental health were investigated in two separate models.

One of the methodological challenges in studying the perceived environment and health with data derived from surveys is that outcome (health) and environmental indicators are measured in the same source (i.e. both are reported by same person), leading to so-called one-source bias, which can compromise the results. For example, some people may tend to generally have more negative perceptions of life, and hence report poorer health and give negative assessments of their surroundings. We mitigated this problem by computing an average perception of each component of the environment (i.e. an averaged measure computed from the answers of all residents of a particular neighborhood). This aggregated measure is less sensitive to individual perceptions, and may therefore be considered to lead to more objective findings. At the same time, the contribution of individual perceptions of the environment to the individual health outcome was taken into account by including a second variable which was computed as the difference between the neighborhood mean and the assessment given by an individual. Thus, each of 18 aggregated indicators of the neighborhood environment was included using two independent variables: (1) the mean for the neighborhood (the mean of scores given by respondents from the same neighborhood) (2) the difference between neighborhoods means and the individual score.

Each aggregated indicator of a neighborhood environment characteristic was modeled separately as an independent variable, in view of the high correlation between the aggregated indicators and the limited power of the model (total number of neighborhoods $n = 39$). Each regression model was adjusted for individual age, gender, education and income group. Additionally, models with health were repeated without adjustment for individual income, observing the change in regression coefficients. Analyses were performed on the complete cases available for each model.

The median odds ratio (MOR) was computed first for the model only adjusted for demographic characteristics (age and gender), then for the model adjusted for demographic and socio-economic characteristics (education and income) and, lastly, for the models that also included one of the 18 neighborhood characteristics. MOR is a tool to estimate the area-level variance. Merlo et al. [17] have defined MOR as the median value of the odds ratio between the area at highest risk and the area at lowest risk. In our study, MOR shows the extent to which the individual probability of reporting poor health is related to residential area [17]. While linear models allow other statistical indicators to be computed for quantifying between-cluster variation, MOR is particularly suitable for models with dichotomous outcomes [18]. MOR takes values between 1 (no differences at group level) and positive infinity.

A sample from another large municipality in Southern Limburg, Heerlen, was used to assess the robustness of the

findings for the factors of neighborhood environment that could be reproduced. The sample came from a survey similar to the one from Maastricht, with the only difference that the number of questions included in the survey was smaller and did not cover as many aspects of the neighborhood environment. Analyses were repeated in this sample and results compared with the main findings.

To explore whether relationships between neighborhood environment and health would be different depending on the demographic or socio-economic characteristics of the individuals, we checked for relevant interactions between the characteristics of the neighborhood environment that showed statistically significant associations with the health outcomes and gender, age, education group and income group.

Statistical significance was set at 0.05 level. The STATA 12 statistical package was used [19].

## Results

### Study Population

A total of 9,879 residents of Maastricht were included in the study (response rate 25 %). Mean age of the respondents was 55 years and 48 % were male. Thirty-nine percent of respondents were highly educated, while 33 % had the lowest level of educational attainment. The sample had a somewhat higher share of highly educated respondents compared to the general Dutch population. Most of the respondents (51.2 %) classified themselves as belonging to the medium income group. In total, 23 % reported their health to be poor or very poor, and 4.4 % reported a score indicative of a high level of depressive symptoms (Table 1).

Thirty-nine neighborhoods were included in the analyses (150–6,305 residents per neighborhood, mean 3,033). Very small neighborhoods with less than 100 residents (n = 3) were excluded.

At neighborhood level, substantial differences in socio-economic and particular health characteristics were observed. The percentage of low-educated individuals varied from 9 to 62 %, and the percentage of residents who perceived their income as low ranged from 1 to 44 %. Up to 40 % of respondents in the neighborhoods reported their health to be poor or very poor, and up to 12 % had a high level of depressive symptoms Table 1).

### Developing Neighborhood Environment Indicators

After reviewing the questionnaire, the study group identified 74 items measuring aspects of the physical (n = 35) or social environment (n = 39). Exploratory factor analyses clustered the variables into 18 conceptually and statistically consistent factors (more than 60 % of the variance being explained by the factors). Sufficient internal consistency was confirmed for each factor (Cronbach's Alphas >0.7) for items that had a factor loading >0.4. Mean scores (SD and range) for each factor are presented in Table 2 (for a detailed overview of the indicators that composed the factors see online appendix 1). Neighborhoods showed to be quite heterogeneous in terms of physical as well as social environment characteristics.

**Table 1** Socio-demographic and health characteristics of the sample (n = 9,879)

| Variable | At individual level Mean (SD), [min–max] N (%) | At neighborhood level Min–max of the neighborhood level indicators |
|---|---|---|
| Age | 55.3 (15.8) [18; 98] | 46.2–59.1 |
| Missing n | 179 (1.8) | |
| *Gender* | | |
| Male | 4,750 (48.0) | 40.9–57.6 % |
| Missing n | 150 (1.7) | |
| *Education* | | |
| Low | 3,279 (39.3) | 9.0–61.5 % |
| Secondary | 2,315(23.4) | 4.2–36.1 % |
| High | 3,886 (39.3) | 13.1–71.0 % |
| Missing n | 399 (4.0) | |
| *Income (self-classified)* | | |
| Low income | 1,993 (20.2) | 1.0–44.3 % |
| Medium income | 5,004 (50.6) | 24.4–71.1 % |
| High income | 2,131 (21.6) | 4.8–70.4 % |
| Missing n | 751 (7.6) | |
| *Self-rated health* | | |
| Poor or very poor | 2,113 (22.4) | 7.3–40.0 % |
| Good, very good, excellent | 7,404 (75.0) | 60.0–92.7 % |
| Missing n | 262 (2.6) | |
| *Depression* | | |
| High level of depression symptoms | 422 (4.3) | 0.0–12.0 % |
| Medium level of depression symptoms | 3,018 (30.5) | 17.1–41.2 % |
| Low level of depression symptoms | 5,904 (59.8) | 48.8–80.5 % |
| Missing n | 500 (5.4) | |

### Neighborhood Environment and Health

Table 3 shows the variation in self-rated health and depressive symptoms between the 39 neighborhoods in

**Table 2** Aggregated indicators of social and physical environment in Maastricht (2010)

| Neighborhood environment indicator | Individual scores Mean (SD) [min–max] | Neighborhood scores Mean (SD) [min–max] |
|---|---|---|
| *Physical environment* | | |
| Quality and availability of parking facilities | 5.42 (2.60) [0;10] | 5.42 (0.71) [3.13;6.94] |
| Quality and availability of daily shopping facilities | 6.75 (2.51) [0;10] | 7.03 (1.44) [0.00;8.59] |
| Reach ability of facilities for daily use | 6.57 (1.85) [0;10] | 6.49 (1.04) [1.50;7.78] |
| Traffic nuisance | 5.64 (2.90) [0;10] | 5.88 (0.87) [1.00;7.42] |
| Quality and availability of green space | 5.96 (2.12) [0;10] | 5.93 (0.47) [4.67;7.50] |
| Quality of bicycle lanes, sidewalks and roads | 5.54 (2.15) [0;10] | 5.05 (0.59)[3.69;6.43] |
| Railway noise nuisance | 9.24 (2.18) [0;10] | 9.37 (0.86) [6.67;10.00] |
| Industrial nuisance | 8.66 (2.46) [0;10] | 8.88 (0.89) [2.50;10.00] |
| Quality and availability of public transport | 7.03 (2.00) [0;10] | 7.12 (0.68) [0.83;8.25] |
| Quality of sewerage | 7.51 (2.04) [0;10] | 7.54 (0.43) [6.35;8.75] |
| Cleanliness | 3.94 (3.03) [0;10] | 3.89 (0.23) [1.67; 5.00] |
| Damage to physical environment | 5.72 (3.69) [0;10] | 5.33 (1.01) [2.50;8.19] |
| *Social environment* | | |
| Social cohesion | 6.91 (1.63) [0;10] | 6.93 (0.59) [5.66;8.02] |
| General nuisance by people | 7.72 (2.08) [0;10] | 7.67 (1.01) [1.25;9.27] |
| General feeling of safety | 7.59 (2.44) [0;10] | 7.58 (0.79) [3.09;8.95] |
| Thefts | 5.92 (2.67) [0;10] | 6.13 (0.95) [4.00;8.52] |
| Performance of police | 2.75 (2.65) [0;10] | 2.82 (0.61) [0.00;4.34] |
| Nuisance by drunk people | 8.35 (2.52) [0;10] | 8.42 (1.12) [3.79;10.00] |

All aggregated indicators of the neighborhood environment were scored 0–10; the higher the score, the more favorable the perception of the situation corresponding to the indicator

**Table 3** Between-neighborhood variation in self-rated health and depressive symptoms

| Model | MOR |
|---|---|
| *Self-rated health (poor vs. good health)* | |
| Empty model (only outcome) | 1.48 |
| Age/gender | 1.48 |
| Age/gender/education | 1.30 |
| Age/gender/income | 1.24 |
| Age/gender/education/income | 1.17 |
| *Level of depressive symptoms (high vs. medium and low)* | |
| Empty model (only outcome) | 1.66 |
| Age/gender | 1.64 |
| Age/gender/education | 1.43 |
| Age/gender/income | 1.33 |
| Age/gender/education/income | 1.26 |

*MOR* median odds ratio

Maastricht. An individual living in the area with the lowest risk would have 1.48- to 1.66-fold higher odds of reporting adverse health when moving to a high-risk area. MOR reduced to 1.17 and 1.26 after adjusting for individual demographic and socio-economic characteristics.

Among the *neighborhood-level* characteristics (means of computed aggregated measures per neighborhood), better general feeling of safety, more social cohesion and less car and railway traffic nuisance were associated with lower odds of having poor self-rated and/or mental health, after adjusting for age, gender and socio-economic status (income and education). A higher score on the safety scale was associated with lower odds of poor self-rated health (OR 0.88 for each point of improvement on a 0–10 safety scale) and depressive symptoms (OR 0.81). Neighborhood social cohesion was significantly associated with self-rated health (OR 0.81) but did not reach statistical significance in the model with mental health as an outcome. On the other hand, residents of neighborhoods with less car traffic nuisance and less disturbance from railways had lower odds of reporting mental health problems (OR 0.79 and 0.85, respectively). We did not observe any association between health and the quality of parking and shopping facilities, facilities for public or private transportation, neighborhood aesthetics, green space, industry nuisance, sewerage, neighbor nuisance, or satisfaction with police performance (Table 4).

Adding neighborhood environment characteristics to the model reduced the between-neighborhood variation in outcomes. Adding each of the neighborhood characteristics resulted in the MOR being decreased to up to 1.07 for self-

**Table 4** Characteristics of physical and social environment in relation to self-rated health and depressive symptoms

| | Neighborhood mean | Individual perception | MOR | Neighborhood mean | Individual perception | MOR |
|---|---|---|---|---|---|---|
| | OR [95 % CI] | | | OR [95 % CI] | | |
| Independent variables[a] | Self-rated health is poor or very poor (vs. good, very good or excellent) | | | High level of depressive symptoms (vs. low or medium level) | | |
| Quality and availability of parking facilities | 1.06 [0.95;1.18] | **0.94 [0.92;0.97]** | 1.17 | 0.91 [0.75;1.09] | **0.92 [0.88;0.96]** | 1.22 |
| Quality and availability of daily shopping facilities | 0.98 [0.93;1.04] | **0.89 [0.87;0.92]** | 1.18 | 0.97 [0.89;1.07] | **0.89 [0.84;0.93]** | 1.26 |
| Reach ability of facilities for daily use | 0.99 [0.92;1.07] | **0.89 [0.86;0.92]** | 1.18 | 0.97 [0.85;1.10] | **0.86 [0.80;0.92]** | 1.25 |
| Traffic nuisance | 0.92 [0.85;1.01] | **0.93 [0.92;0.95]** | 1.16 | **0.79 [0.68;0.92]** | **0.86 [0.83;0.90]** | 1.22 |
| Quality and availability of green space | 0.92 [0.78;1.07] | **0.94 [0.92;0.97]** | 1.16 | 0.83 [0.62;1.11] | **0.92 [0.88;0.97]** | 1.24 |
| Quality of bicycle lanes, sidewalks and roads | 0.91 [0.80;1.04] | **0.94 [0.92;0.96]** | 1.16 | 0.87 [0.68;1.11] | **0.93 [0.89;0.98]** | 1.27 |
| Quality and availability of public transport | 1.04 [0.93;1.16] | **0.90 [0.87;0.93]** | 1.16 | 1.01 [0.82;1.25] | **0.86 [0.82;.91]** | 1.27 |
| Cleanliness | 0.89 [0.64;1.24] | 1.00 [0.98;1.02] | 1.17 | 0.95 [0.50;1.82] | 1.01 [0.97;1.05] | 1.27 |
| Damage to physical environment | 0.96 [0.89;1.04] | 1.00 [0.98;1.01] | 1.18 | 0.94 [0.81;1.10] | 0.98 [0.95;1.01] | 1.27 |
| Railway noise nuisance | 0.98 [0.89;1.08] | 0.96 [0.93;1.00] | 1.20 | **0.85 [0.73;0.99]** | **0.92 [0.87;0.98]** | 1.26 |
| Industry nuisance | 1.02 [0.94;1.11] | **0.96 [0.93;0.99]** | 1.15 | 0.91 [0.78;1.06] | **0.92 [0.88;0.97]** | 1.24 |
| Quality of sewerage | 0.85 [0.71;1.01] | **0.92 [0.89;0.94]** | 1.16 | 0.80 [0.59;1.07] | **0.89 [0.85;0.93]** | 1.20 |
| Social cohesion | **0.81 [0.72;0.92]** | **0.87 [0.84;0.91]** | 1.12 | 0.81 [0.64;1.03] | **0.81 [0.76;0.87]** | 1.18 |
| General nuisance by people | 0.94 [0.86;1.02] | **0.91 [0.88;0.94]** | 1.13 | 0.90 [0.78;1.04] | **0.81 [0.76;0.86]** | 1.10 |
| General feeling of safety | **0.88 [0.80;0.97]** | **0.88 [0.86;0. 90]** | 1.16 | **0.81 [0.69;0.97]** | **0.81 [0.78;0.85]** | 1.21 |
| Thefts | 0.92 [0.85;1.00] | **0.95 [0.92;0.97]** | 1.07 | 0.87 [0.75;1.01] | **0.87 [0.82;0.92]** | 1.00 |
| Performance of police | 0.85 [0.73;1.00] | **0.96 [0.93;0.99]** | 1.19 | 1.07 [0.85;1.34] | 0.94 [0.89;1.00] | 1.00 |
| Nuisance by drunk people | 1.01 [0.95;1.09] | **0.94 [0.92;0.97]** | 1.18 | 0.94 [0.84;1.06] | **0.88 [0.84;0.91]** | 1.25 |

Coefficients from logistic regression model adjusted for individual age, gender, education and income group. Estimates with $p$ value <0.05 are highlighted in bold

[a] All aggregated indicators of neighborhood environment are scored 0–10; the higher the score, the more favorable the perception of the situation corresponding to the indicator

rated health and 1.0 for depressive symptoms. Safety-related indicators (perceived frequency of thefts and satisfaction with police performance) were among the factors that explained most of the between-neighborhood variation.

At the level of *individual perception*, most of the neighborhood characteristics studied were associated with individual self-rated health and depressive symptoms, and the direction of the associations followed the patterns described above for neighborhood-level characteristics. Quality and availability of parking and daily shopping facilities, reachability of facilities for daily use, traffic nuisance, satisfaction with green space, facilities for public and private transportation, quality of sewerage, social cohesion, nuisance and safety perceptions were significantly associated with both general self-rated and mental health (OR between 0.88 and 0.96). Additionally, individual perceptions of railway noise were related to depressive symptoms (OR 0.85) (Table 4).

Similar models, but not adjusted for income, yielded generally higher estimates for the association between neighborhood indicators and health outcomes (online appendix 2). The directions of associations persisted when the models were repeated with social cohesion and feelings of safety (which were significant in the first round of analyses, and for which comparable aggregated indicators of neighborhood environment were available) as independent variables and self-rated health as an outcome in the sample from Heerlen (Online appendix 3).

There were no significant interactions between neighborhood safety, social cohesion or traffic nuisance and gender, age, education or income.

## Discussion

Our study explored a comprehensive set of neighborhood environment characteristics in relation to the health of the residents, by aggregating a large amount of routinely

collected survey data. We observed a large variation in self-rated health and the presence of depressive symptoms between neighborhoods, which persisted even after adjusting for individual age, gender, education and income. This suggests that other contextual factors may be responsible for the remaining variation. A closer look at the characteristics of the neighborhood environment shows that residents who live in areas with a higher level of safety, less traffic and railway noise nuisance and higher social cohesion tended to report better general and mental health, regardless of their age, gender and socio-economic position (as measured by education and income group). One point of improvement in these neighborhood factors (all measured on a 0–10 scale) corresponded to 12–21 % lower odds of reporting poor health. Adding neighborhood characteristics helped to explain the between-neighborhood variation further, and this was particularly relevant for neighborhood social environment aspects. The effect of these neighborhood features on health did not vary across gender, age or SES groups (education and income).

With regard to feelings of safety, we found a clear indication that residents tend to be healthier in safer neighborhoods. Other studies have previously obtained similar findings in Sweden and different sub-populations in the USA [20–23]. However, there is no agreement about this in the research literature, and some studies did not find any relationship between neighborhood safety measures and health, including one study conducted in another Dutch city [10, 11]. There is great heterogeneity in measures of safety, which may to some extent be responsible for the contradictory findings. We have composed a few distinct measures of safety and social order, and only a general feeling of safety was consistently found to be relevant to health outcomes-as residents were both mentally and physically healthier in safer communities.

Social cohesion, which in various operationalizations represents trust, social support, tolerance and quality and quantity of social connections, is becoming one of the neighborhood attributes that are internationally increasingly being recognized as relevant [24–26]. Our findings indicate that residents in more cohesive neighborhoods report better self-rated health, and this is largely supported by the available literature [24, 27, 28]. Surprisingly, we did not observe this relationship for mental health outcome (high level of depressive symptoms) even though physiological processes are expected to play an important role in the pathway between the social capital and health [25]. Although this relationship is commonly hypothesized, few studies have actually explored the relationship between social capital and mental health and found positive associations [27, 29–31]. It is important to mention that differences in findings may also lie in multiple ways of operationalizing and measuring community social cohesion and social capital (with no agreement in terminology or measurement among researchers) and mental health outcomes in different studies. However, it might well be that macro-contexts (i.e. beyond the neighborhood) play a role and are accountable for the discrepancies between the findings. Further research is needed to allow more definitive conclusions.

Traffic noise nuisance has recently started to receive more attention from public health researchers, with the growth and increased intensity of urbanization areas. Out of a broad range of aspects of the neighborhood environment that we explored in this study, nuisance from car traffic and railways appeared to be among the few factors relevant to mental health, indicating that residents of neighborhoods with more noise nuisance are more likely to have mental health complaints. Previously, Banerjee et al. [32] linked traffic noise to a higher risk of coronary heart disease. A cohort study by Bocquier et al. [33] showed that traffic noise at night leads to higher purchases of psychotropic drug . Few other studies have linked traffic noise to health-related quality of life [34, 35]. Researchers suggest several pathways between exposure to noise and health, and psychosocial and stress-related mediators are among them [36, 37]. Compared to existing studies, our indicator of car traffic nuisance was broader and included not only noise but also other components such as smell and aggressive driving.

One of the methodological strengths of our study is that our modeling strategy was able to simultaneously account for both area-level neighborhood characteristics and individual perception of a neighborhood. To our knowledge, this has not been done before, and our study adds to previous research which either used individual perceptions only, or a mean score for all residents of the neighborhood but without adjusting for individual perceptions, or objective data on neighborhood environment coming from an independent source [10, 38, 39]. Another particular strength of our study is the practical decision to reduce the number of available indicators to a reasonable number of meaningful concepts. To our knowledge, only one study has previously raised the problem of dealing with a variety of indicators and their aggregation, and it dealt with this in a comparable approach [40]. Furthermore, our study is one of the few to have explored a nearly comprehensive list of perceived environment indicators studied in relation to both mental and general health. We were able to partially replicate our results by means of similar survey data from another large municipality in South Limburg, which increases the robustness of our findings (online Appendix 3). Among previous studies, similar work has been done in the UK by Cummins et al. [11] covering a number of concepts relating to neighborhood environment. Although the sets of concepts may overlap at first sight, the actual

content depends on national context. Also, routinely available data are based on different questions according to international differences. We have used MOR to additionally explore the variation in health between neighborhoods. As expected, individual socio-economic status played a dramatic role in health disparities, and adjusting for only a few SES factors substantially reduced the variation among neighborhoods. Computing MOR for each model adjusted for one of the 18 neighborhood characteristics revealed that aspects relating to safety were among the factors that explained most of the variation between the neighborhoods.

There is an ongoing discussion in the scientific literature about defining the size and borders of area of residence for health studies. This is not a straightforward concept, and researchers use various units based on historical or administrative boundaries, people's characteristics or people's perceptions, and units may also differ depending on research questions [41, 42]. In the Netherlands, health policy is often being tailored to the neighborhoods in administrative terms ("buurt- of wijkaanpak") [12]. Neighborhood appears to be acceptable from both conceptual (boundaries between neighborhoods are generally defined based on historical and not purely administrative grounds) and practical (it is possible to assign each individual to an area based on postal code) points of view [10, 42–46]. It is important to point out that in a number of previous studies which used Dutch national samples, researchers were only able to use the 4-digit postal code area as a proxy for neighborhood, which in reality may correspond to more than one neighborhood in one geographical area [8, 9]. Our sample was large enough to distinguish the neighborhood level. A recent Dutch study by Veldhuizen et al. [47] presented an analysis of relationships between socio-economic variables and health at different area sizes, and suggested that administrative areas that are defined on the basis of socio-economic and geographic criteria (such as neighborhoods in our case) may function well.

It is important to reflect on the role of income in analyses of neighborhood environment and health. We considered that income might be a confounder and adjusted the models for individual income groups. However, we recognize that (average neighborhood) income may also be a part of the pathway from exposure to outcome between neighborhood factors and health and as such, adjustment might lead to overadjustment, as shown by Schisterman et al. [48]. An intermediary role of income in between-neighborhood differences in environment and health is likely, as a neighborhood with poor environmental characteristics is likely to have lower house prices, thus attracting low income residents, which relates to a poorer neighborhood health. Controlling for the intermediary variable would then lead to an inconsistent estimate of the causal effect. Removing income from the models indeed led to stronger relationships between neighborhood environment features and the health of the residents, and to more environment factors reaching statistical significance (Online appendix 2). It is a question for future research to explore the causal pathways between the environment, income and health.

This study had several limitations. First, it is important to remember that there are two ways to explain how poor health and neighborhood deprivation are related: the selection approach (people in poor health move towards deprived areas; this pathway is also called compositional) and the causation approach (deprived areas have an unhealthy effect on inhabitants, also called contextual explanation) [49]. Recent studies showed, however, that migration does not seem to have major consequences for neighborhood health, which does not support the notion of a selection mechanism [9, 50]. This gives us additional arguments to infer a causal effect in relationship between neighborhood and health. The second limitation was that the survey data were self-reported, with possible implications for accuracy. Data on income were of particular concern, because it was self-classified into one of the three categories (low, medium, high), and may therefore reflect a relative (compared to others) rather than objective income. Furthermore, there was a relatively high number of missing values for this compared to other variables (7.6 %). In the abovementioned sensitivity analyses, where we excluded income from the models, the direction of the associations persisted, which suggests that the results were not seriously compromised by this limitation.

Despite the limitations we faced, we were able to explore a very comprehensive set of neighborhood environment measures and shed light on those that are most proximate to the health of the residents. We have been able to mitigate methodological difficulties relating to one-source bias and to make use of a large amount of routinely collected neighborhood data. Our findings suggest that a people living in neighborhoods with a higher level of safety, less car and railway traffic nuisance and higher social cohesion tend to self-rate their health as good and/or have better mental health, regardless of their demographic status and socio-economic position. In Netherlands, it is to a large extent the responsibility of municipal authorities to improve the health and well-being of the residents. Southern Limburg municipalities have developed a policy vision that recognizes that both individual factors and the living environment (in a number of domains such as safety, spatial planning, care, education etc.) affect the health of residents [12, 51]. Such policy is expected to both improve the overall health and well-being of the residents and reduce health inequalities by tackling a number of social

determinants of health in disadvantaged neighborhoods. Our findings can underpin these policies with evidence regarding the neighborhood features that offer the greatest potential for action in efforts to improve health.

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