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Effects of changing exposure to neighbourhood greenness on general and mental health: A longitudinal study

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ABSTRACT

Green neighbourhood environments have been associated with physical and psychological wellbeing in adults. Access to greenness is potentially more important in vulnerable subgroups. In this study based on longitudinal survey data from southern Sweden the cohort was divided into prognostic groups for good self-reported general ($n=8891$) and mental ($n=9444$) health. We used independent survey data to assess perceived neighbourhood greenness in 1 km^2 areas, and estimated effects of changing exposure longitudinally stratified by prognostic group. The overall effect on health was small and statistically uncertain (for general health OR 1.04, 95% CI 0.98–1.10, for mental health OR 1.07, 95% CI 1.00–1.14). A more beneficial effect of increased greenness was indicated among subjects with lowest prognostic of good general health (OR 1.24, 95% CI 1.01–1.52). The study provided only weak evidence for beneficial effects of increased neighbourhood greenness triggered by changing residence. It seems that altered life circumstances, e.g. changed civil or socioeconomic status that often trigger a decision to move, are also the key determinants of the health consequences of changing residence.

1. Introduction

Availability and quality of green areas in neighbourhood environments have been associated with general and mental health (Alcock et al., 2014; Björk et al., 2008; Bowler et al., 2010; de Jong et al., 2012; Maas et al., 2006; Stigsdotter et al., 2010; Sugiyama et al., 2008; van Dillen et al., 2011; White et al., 2013). The Attention Restoration Theory, presented in the mid-1990s, proposed an original rationale for associations between green environments and health by suggesting that restoration from fatigue, caused by an overload of directed attention, can be obtained in natural environments (Kaplan, 1995). The effect of greenness in neighbourhood environments on health may differ across population groups and individual living conditions. Results from the UK suggest a stronger beneficial effect from exposure to green space on disease risk and mortality in low-income groups (Mitchell and Popham, 2007, 2008). Studies from southern Sweden also suggest a positive influence of nature on the health of particularly vulnerable groups such as elderly people (Ottosson and Grahn, 2006), individuals in rehabilitation for stress-related mental disorders (Pálsdóttir, 2014) and individuals in crisis rehabilitation (Ottosson and Grahn, 2008).

Although there are some recent longitudinal ones (Alcock et al., 2014; Annerstedt et al., 2012; White et al., 2013), previous epidemiological studies on green space and health have mainly used cross-sectional designs and are therefore unable to provide evidence about causality. In particular, cross-sectional designs are prone to self-selection bias, i.e. that individuals with higher well-being choose to live in neighbourhoods that support a healthy lifestyle (Katz, 2009). Moreover, cross-sectional studies are also prone to single source bias, if data on exposure and health status are both based on self-assessments (de Jong et al., 2012). One solution to this latter problem would be to use objective assessments of the neighbourhood environment based on landscape data (Björk et al., 2008). However, there are evidence suggesting that perceptions of the neighborhood, e.g. as being green, walkable or noisy, are important for health, also after controlling for objective measures of identical or similar features (Babisch et al., 2013; de Jong et al., 2012; Gebel et al., 2011; Prins et al., 2009; Van Dyck et al., 2014) The problem of single source bias in studies of the perceived environment can be avoided by using neighbourhood assessments based on an independent sample from the same

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study area (Auchincloss et al., 2009). Addressing causality issues would also require a longitudinal design with repeated measurements of both exposure and outcome, and that a considerable proportion of study individuals change their exposure (typically by moving to another residential area) during follow-up.

Studying heterogeneity of exposure effects is potentially problematic with an inflated risk for false positive findings when a large number of subgroups are investigated. Risk stratification, i.e. grouping the study individuals according to their risk for the outcome (e.g. a certain disease or declined health), is in other areas of epidemiological and clinical research a common approach to investigate heterogeneity of exposure effects or treatments while limiting the number of subgroups (Hansen, 2008; Singbartl and Kellum, 2012). This approach has however seldom been applied in studies of health in relation to neighbourhood green space.

The aim of this study was to assess the effect of changes in exposure to the quality of neighbourhood greenness, triggered by changing residence, on self-reported general and mental health using random effects logistic regression. We used a longitudinal design with repeated survey data from southern Sweden in the years 2000, 2005 and 2010 for the data on health and covariates, and a separate cross-sectional survey in year 2008 for the data on exposure. We modelled the probability of good general health and good mental health, respectively, cross-sectionally based on available covariates in 2000 using logistic regression. We then stratified the cohort according to these fitted prognostic scores at baseline. Effects of changes in greenness exposure was assessed for each prognostic score group separately using random effects logistic regression. We hypothesised that the effect was more marked in the groups with lowest prognostic scores of good general and mental health, respectively.

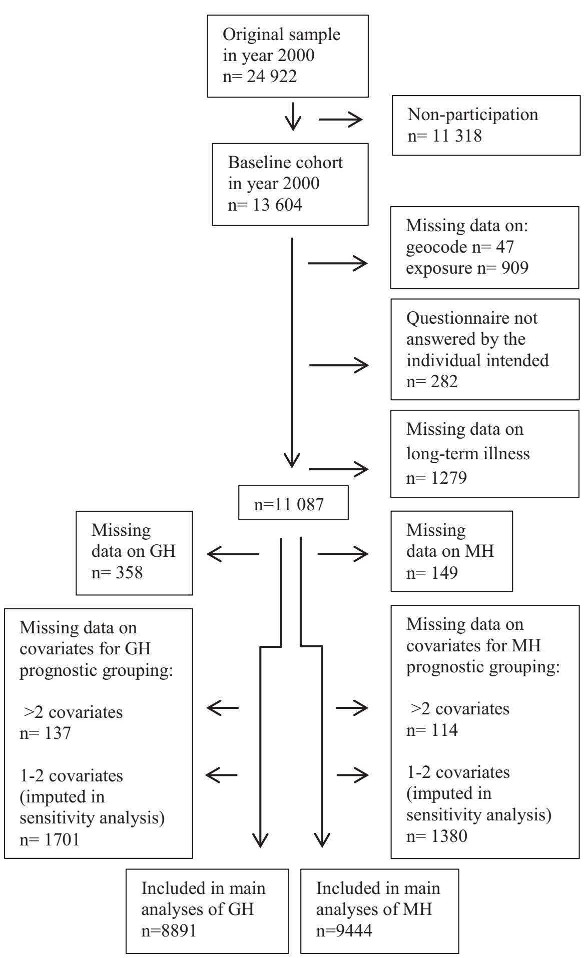

Fig. 1. Flowchart showing exclusions and inclusions at baseline. For analyses of general health (GH) and mental health (MH).

2. Method

2.1. Survey participants

This study was based on data from a longitudinal public health survey conducted in southern Sweden in 2000, with follow up surveys for the same cohort in 2005 and 2010. The study population at baseline consisted of all inhabitants aged 18–80 years that was registered in the Scania region (Skåne) in November 1999. The population was stratified by geographical area, age and sex into 60 strata. For each stratum, approximately 400 individuals were randomly selected from the population registry (Carlsson et al., 2006). The baseline questionnaire consisted of 106 questions and was mailed to 24 922 individuals in November 1999. After three postal reminders and one reminder by telephone a total of 13 604 participants (55%) had answered the questionnaire (Östergren et al., 2000). In September 2005 and 2010, the questionnaire was sent to the original responders in 2000 who were still alive and residing in Scania ($n=12\,504$ in 2005 and $n=11\,652$ in 2010). The number of respondents in 2005 and 2010 was 10 475 (84%) and 9031 (78%), respectively. The questionnaire in 2005 was identical with the one sent out in 2000. The questionnaire in 2010 included eight additional questions but was otherwise identical with the previous questionnaires. In the present study, all respondents to the survey at baseline (year 2000) are part of the baseline cohort regardless of whether these persons also responded to the questionnaires in year 2005 and 2010.

The longitudinal design requires that the questionnaires are answered by the same individual over time. Responders who did not report the same sex and year of birth at baseline as noted in the population registry were excluded ($n=282$) since we then assumed that the questionnaire was not answered by the individual intended. Additional reasons for exclusion from the study cohort at baseline were missing data on geocoded residential address ($n=47$), neighbourhood green qualities ($n=909$) in the 1 km^2 area the residence was located in (see below) or variables in the questionnaire that were needed to determine prognostic group, general health or mental health (Fig. 1).

2.2. Exposure-assessment of neighborhood green qualities

Factor analysis based on extensive interview studies conducted within the field of environmental psychology and landscape architecture has identified eight different qualities in park environments that are particularly appreciated by humans (Grahn, 1991; Grahn and Stigsdotter, 2010). In this paper, we used data obtained from a separate cross-sectional public health survey ($n=28\,198$) with similar age, sex and geographical distribution as in the longitudinal cohort, conducted in Scania in year 2008 (Rosvall et al., 2009). This cohort answered a questionnaire including a question about the presence within 5–10 min walking distance from their home of five of the qualities, here referred to as serenity, wildness, species richness, spaciousness and cultural history. The question was phrased: "Think of nature within 5–10 min walking distance from where you live. For example this can be green spaces, parks or forest areas. Do you agree with the following statements?" followed by five statements: "Nature in the area where I live… a) is quiet, one can hear nature's own sound, b) is wild, it has developed without human impact, c) has a large diversity of animal and plant species, d) is a large cohesive area, e) makes you feel the historical heritage, for example ancient monuments, old trees and constructions".

Each of these five items was rated on a 4-graded ordinal scale: 1=Disagree completely, 2=Disagree, 3=Agree, 4=Agree completely. There was also a fifth option, 5=Do not know/cannot say. Answers 1 and 2 were regarded as positive assessments (quality present) in the neighborhood whereas answers 3–5 and missing answers were regarded as negative assessments.

Individual perceptions of the five green qualities from the independent survey in 2008 were available from 28016 respondents residing in 3656 different 1 km^2 areas. For each item we estimated the proportion of positive assessments in each 1 km^2 area using a random effects logistic regression (ecometric) model with adjustment for sex, age, highest level of education, economic difficulties, country of origin and type of residence using the same method as previously described (see de Jong et al., 2011 for modelling details). Note that we included also those respondents living in the inner city areas of the four major cities in Scania, $n=3169$ (excluded in de Jong et al. 2011, 2012). We calculated Scania Green Score (SGS) for each 1 km^2 area as the sum of the five estimated area-level proportions, standardized (mean=0, standard deviation=1) across all 3656 1 km^2 areas.

In the present study we retrieved the geocoded residential address for each survey participant at three time points (year 2000, 2005 and 2010) corresponding to when the surveys were sent out. Each survey answer was assigned the SGS of the 1 km^2 area in which the participant was residing at that time. In total, survey answers in the present study were linked to 1788 different 1 km^2 areas.

2.2.1. *Outcome - general health*

The primary outcome measure in this study was general health (GH), here reflecting physical and psychological well-being. To increase specificity in the assessment of good GH we combined two survey questions. Each question was dichotomized separately and then combined into one dichotomous variable. The first question, phrased as; "How do you rate your physical and mental health at present?" had a seven-point scale ranging from 1 ("very bad, could not feel worse") to 7 ("very good, could not feel better") and was dichotomized as positive (good GH) if the answer was 6 or 7 and negative (poor GH) if the answer was between 1 and 5. The second question, phrased as; "How is your present health status in general?" had five possible answers and was dichotomized as positive (good GH) if the respondent had answered "very good" or "good" and negative (poor GH) if the answer was "fairly good", "bad" or "very bad". The requirement for having good GH in this study was to have answered positively on both these two questions.

Table 1
Background characteristics relevant for prognostic of good general health (GH) at baseline in 2000, stratified for four prognostic groups with (1) or without (0) long-term illness and with a likelihood of having good GH below (−) or above (+) median. Characteristics tested but not relevant for prognostic of good GH was high alcohol consumption and having children under age 25 living at home. In addition, distribution of exposure (standardized SGS) and outcome measures (general health and mental health) are presented.

			Long-term illness			
			Yes		No	
			GH prognostic group			
		Total	1−	1+	0−	0+
	n	8891	1236	1244	3228	3183
Background characteristics		%	%	%	%	%
Sex	Male	48	30	64	28	68
Age group	18–34 years	26	18	23	27	28
	35–49 years	29	36	16	38	23
	50–64 years	30	33	32	26	32
	65–80 years	15	13	29	9	17
Body mass index	< 18,5	2	3	1	3	0
	18,5–24,9	55	41	57	50	65
	25–29,9	34	35	38	33	33
	≥ 30	9	21	4	14	2
Smoker	No	77	60	87	68	89
Civil status	Married/cohabiting	71	56	80	60	85
Born in Sweden	Yes	90	83	96	83	98
Type of housing	Own townhouse or villa	65	46	79	50	83
	Apartment or other	35	54	21	50	17
Problem paying bills	Never or occasionally	91	72	100	85	100
	Always or often	9	28	0	15	0
Educational level	University	40	25	46	31	52
	High school	32	38	24	40	25
	Primary /secondary school	28	37	30	29	23
Occupation	Working	66	45	60	67	76
	Retired	19	35	29	12	16
	Student or unemployed	15	20	11	21	8
Exposure						
Standardized SGS[a]	> 0	25	20	32	21	29
	0 to −1	14	15	13	13	16
	−1 to −2	23	23	23	23	23
	≤ −2	38	43	32	43	33
Outcomes						
Good general health	Yes	44	18	30	46	57
Good mental health ($n=8844$)	Yes	82	64	80	82	90

[a] Expressed as number of standard deviations from mean. SGS=Scania Green Score.

2.2.2. Outcome - mental health

The secondary outcome measure used in this study was mental health (MH), reflecting psychological well-being. We used the 12 item General Health Questionnaire (GHQ-12) (Goldberg, 1972). GHQ-12 items include both positive and negative mental health states, such as feeling useful and being able to concentrate and feeling under strain and having problems sleeping due to anxiety, with four possible answers on each item. The answer on each question was dichotomised (coded 0 if the answer indicated positive mental health and 1 if the answer indicated negative mental health), added to a sum score and grouped to express good (sum score 0–2) or poor (sum score 3–12) MH.

2.3. Prognostic groups for good general and mental health

Using data on outcome and other covariates, except the exposure, at baseline in 2000, we modelled the probability of each outcome, good general health and good mental health, separately, using logistic regression. All items included in the questionnaire that we considered to be potentially relevant for any of the two outcome measures were tested in univariate analyses. Variables with univariate p-Value ≤ 0.10 were combined in a multiple logistic regression model and kept if the p-Value ≤ 0.05 in the final prognostic score model for each outcome (Tables 1 and 2). Consistent with previous work (Hansen, 2008), we refer to these fitted probabilities as prognostic scores, although they were modelled cross-sectionally at baseline in our study. The prognostic scores were used for confounding control, but also to assess effect modification by stratifying the cohort according to the prognostic scores at baseline.

Long-term illness (present among 28% of all participants at baseline) was strongly associated with good GH. When forming the prognostic groups, the cohort was therefore first divided into two clusters dependent on having answered yes (1) or no (0) on the question about having long-term illness. These two clusters

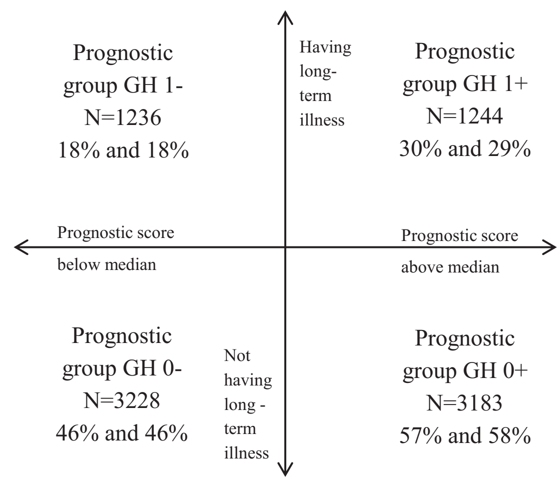

Fig. 2. Illustration of how the baseline cohort was classified into four prognostic groups with (1) or without (0) long-term illness and with a likelihood of having good general health (GH) below (−) or above (+) median. Values in per cent represent, for each prognostic group; the actual and the estimated proportions of good GH.

Table 2
Background characteristics relevant for prognostic of good mental health (MH) at baseline in 2000, stratified for four prognostic groups with (1) or without (0) long-term illness and with a likelihood of having good MH below (−) or above (+) median. Characteristics tested but not relevant for prognostic of good MH was body mass index and educational level. In addition, distribution of exposure (standardized SGS) and outcome measures (general health and mental health) are presented.

			Long-term illness			
			Yes		No	
			MH prognostic group			
		Total	1−	1+	0−	0+
	n	9444	1317	1329	3481	3317
Background characteristics		%	%	%	%	%
Sex	Male	47	34	59	28	67
Age group	18–34 years	25	34	6	43	10
	35–49 years	29	31	20	39	21
	50–64 years	30	32	33	17	42
	65–80 years	16	2	41	1	27
High alcohol consumption	0–2 days/week	77	89	99	88	99
	3 days or more/week	23	11	1	12	1
Civil status	Married/cohabiting	93	54	83	58	87
Born in Sweden	Yes	71	81	97	84	97
Type of housing	Own townhouse or villa	65	50	75	53	80
	Apartment or other	35	50	25	47	20
Problem paying bills	Never or occasionally	91	73	100	85	100
	Always or often	9	28	0	15	0
Occupation	Working	66	48	56	70	73
	Retired	20	23	43	3	26
	Student or unemployed	14	30	1	27	1
Children at home	No	60	59	73	47	70
Exposure						
Standardized SGS[a]	> 0	25	22	29	22	28
	0 to -1	14	14	13	13	16
	-1 to -2	23	21	25	22	23
	≤ -2	38	43	32	43	33
Outcomes						
Good mental health	Yes	82	63	82	80	92
Good general health (n=9201)	Yes	44	19	27	47	56

[a] Expressed as number of standard deviations from mean. SGS=Scania Green Score.

were then divided further dependent on whether the individual fitted probability was below (−) or above (+) the median in each of the two groups. Four prognostic groups; GH 1−, GH 1+, GH 0− and GH 0+ were thus defined for GH (Fig. 2). Group GH 1− was least likely to have good general health and group GH 0+ was most likely. For MH, long-term illness was not of the same importance but the same pattern for division into prognostic groups was nevertheless applied: MH 1−, MH 1+, MH 0− and MH 0+ (Fig. 3). The participants remained in their initial prognostic groups at follow up, but changes in the prognostic score, trigged by changes in the covariates associated with general or mental health, were adjusted for in the analyses (see next section).

2.3.1. Statistical analysis

The statistical analyses were conducted in SPSS, version 20.0 (IBM Corp., Armonk, NY). The associations between greenness exposure, GH and MH were modelled using random effects logistic regression for each prognostic group separately with a random intercept on the individual-level. Individual difference in the prognostic score, defined as the difference between individual prognostic score and the mean value within the prognostic group at each time point (year 2000, 2005 and 2010), was included as a covariate. Note that this covariate aims to capture changes in life circumstances e.g. changed civil or socioeconomic status, during follow up. Main analyses were based on complete cases (Fig. 1). To estimate the concurrent effect of neighbourhood green qualities on health, we used two exposure measures: 1) the mean SGS ($SGS_{Average}$) of each individual during follow-up and 2) the difference between the exposure at each time point and the mean SGS of each individual ($SGS_{Current} - SGS_{Average}$). These two measures are independent from each other and were included simultaneously in the model. The aim of estimating the inter-individual association from $SGS_{Average}$ was to account for the self-selection effect likely to be present (i.e. that people who are in good health also are more prone to choose to live in neighbourhoods with more green qualities). The assessment of $SGS_{Current} - SGS_{Average}$ (i.e. the difference between an individual's SGS score on each measurement occasion and their average SGS score on all measurement occasions) aims to investigate the intra-individual effect on health status related to change in greenness exposure by moving during follow up. The same idea has been used in sibling studies where family mean exposure and difference from family mean was used to separate inter- and intra-family associations

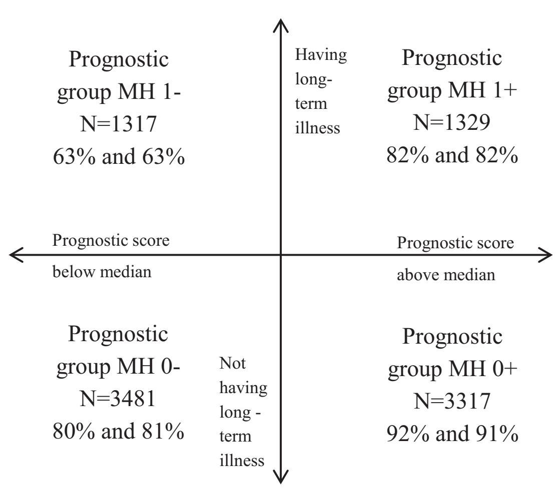

Fig. 3. Illustration of how the baseline cohort was classified into four prognostic groups with (1) or without (0) long-term illness and with a likelihood of having good mental health (MH) below (−) or above (+) median. Values in per cent represent, for each prognostic group, the actual and the estimated proportions of good MH.

(Kuja-Halkola et al., 2010). We tested the homogeneity of the effect between the prognostic groups using chi square test. Results for the total cohort were obtained by weighting the group specific estimates with the inverse of the standard error of each estimate.

2.3.2. Sensitivity analysis using imputation

A substantial proportion of the survey respondents had missing data on some of the variables used in the multivariable prognostic models and was therefore not included in the main analyses. However, most respondents had only one or two missing values, which were imputed as a sensitivity analysis using single imputation (Donders et al., 2006). Respondents with missing data on long-term illness were not subject to imputation. After imputation, the cohort was divided and analysed in prognostic groups using the same criteria, numerical cut-offs for the prognostic scores and statistical modelling strategy as in the main analyses. Consequently additional individuals were included in each prognostic group, but no redistribution between groups took place.

2.3.3. Sensitivity analysis using a less strict definition of general health

As an additional sensitivity analysis we defined physical and psychological wellbeing using only the second of the two questions about GH (with five ordinal levels; see above) in the survey. A new prognostic modelling was conducted based on this less restrictive definition of GH, and prognostic groups were formed using the same principles as before. We estimated the exposure effect on dichotomized GH using logistic regression and on GH as an ordinal scale with 5 levels using ordinal regression.

3. Results

3.1. Determinants of the prognostic for good GH and MH

The final prognostic model for good GH at baseline included 11 socio demographic and lifestyle characteristics associated (p-Value ≤ 0.05) with general health: sex, age, long-term illness, body mass index, smoking habits, civil status, country of origin, type of housing, problems with paying bills, educational level and occupation (Table 1). The corresponding model for MH did not include body mass index and educational level, but included high alcohol consumption and having children under the age of 25 living at home (Table 2). Pronounced differences in prevalence of good self-reported health between prognostic groups were seen for sex, with females generally being less prone to report good GH and MH compared to males. Problems with paying bills stand out as another divider between prognostic score above and below median. Neighbourhood greenness (not included in the prognostic models) was clearly positively associated with the prognostic for good GH and MH at baseline both among subjects with and without long-term illness.

3.2. Characteristics of movers and non-movers

Among the total cohort, about 28% changed residency, either one or multiple times, during follow-up. The only clear difference in characteristic observed between movers and non-movers overall was age, with movers generally being younger than non-movers, albeit some variables that may be related to age, such as educational level and type of housing, had a similar pattern. Long term disease was not independently associated with changing residence.

For GH the proportion of responders that changed exposure during follow-up was of similar magnitude across prognostic groups. For MH individuals in groups with a prognostic below

Table 3
Associations over time between Scania green score (SGS) and good general health (GH) for prognostic groups at baseline in 2000 with (1) or without (0) long-term illness and with a likelihood of having good GH below (−) or above (+) median. The presented effect estimates from generalised linear mixed models imply the odds ratio for good GH for each increase of the standardized SGS equal to one standard deviation.

General Health			Inter-individual association				Intra-individual effect			
				$SGS_{Average}$[a]				$SGS_{Current} - SGS_{Average}$[b]		
		Prognostic group	*n*[c]	OR	95% CI	*p*-Value	*n* (%)[d]	OR	95% CI	*p*-Value
Long-term illness	Yes	GH 1−	1236	0.94	0.87–1.03	0.20	370 (30)	1.24	1.01–1.52	0.04
		GH 1+	1244	0.98	0.92–1.05	> 0.30	337 (27)	1.00	0.84–1.18	> 0.30
	No	GH 0−	3228	1.03	0.99–1.07	0.18	1056 (33)	1.08	0.98–1.18	0.12
		GH 0+	3183	1.06	1.02–1.10	0.01	832 (26)	0.98	0.89–1.08	> 0.30
		Total[e]	8891	1.03	1.00–1.05	0.04	2595 (29)	1.04	0.98–1.10	0.20

[a] Mean SGS during follow-up (year 2000–2005–2010).
[b] Difference between SGS at each survey time point (year 200, 2005 or 2010) and the mean SGS during follow-up.
[c] Number of individuals with complete data in each prognostic group at baseline in 2000.
[d] Number (%) of all individuals with complete data at baseline in 2000 that changed SGS exposure during follow up.
[e] Weighted by the inverse of the standard error of each group-specific estimate.

the median did to a larger extent change exposure during follow-up regardless of the presence or non-presence of long-term illness.

3.3. Associations with general health

Subjects exposed to more neighbourhood green qualities on an average during the study period had higher odds of good GH (OR 1.03, 95% CI 1.00-1.05). This inter-individual association was more noticeable among subjects without long-term illness (p for heterogeneity=0.06). The intra-individual effect of moving to a greener neighbourhood on good GH was weak overall and statistically uncertain (OR 1.04 for each standard deviation change in SGS, 95% CI 0.98–1.10; Table 3). No clear evidence of differential effects across the prognostic groups was discerned (p for heterogeneity=0.18). If anything, a more marked positive effect of greenness was observed among individuals with lower prognostic of good GH, most apparent in the group (GH 1−) with long-term illness (OR 1.24, 95% CI 1.01–1.52) but less apparent in the group (GH 0−) without long-term illness (OR 1.08, 95% CI 0.98–1.18).

3.4. Associations with mental health

The inter-individual association between average exposure to neighbourhood greenness during follow up and the odds of good MH was of similar magnitude to GH (OR 1.03, 95% CI 1.00–1.06). However the size of the association was similar across prognostic groups (p for heterogeneity > 0.30). The overall intra-individual effect of changing greenness exposure on good MH was likewise weak and statistically uncertain (OR 1.07, 95% CI 1.00–1.14; Table 4). No obvious heterogeneity in the effect of moving was noted across the prognostic groups ($p > 0.30$).

3.5. Effect size illustrated by a hypothetical example

The effect on GH associated with a change of exposure to greenness can be illustrated by a hypothetical example. For prognostic group GH 1− the odds ratio was 1.24 (95% CI 1.01–1.52; Table 3). For an individual in this group who moves to an area where the standardized SGS is one standard deviation higher than before, the odds for this individual to have good GH increases with a factor 1.24, or from 17% to 20% when expressed as probabilities. For interpretation; a change of the standardized SGS equal to one standard deviation is roughly comparable to a one step shift between groups of standardized SGS in Tables 1 and 2.

3.6. Sensitivity analyses

The intra-individual effects after imputation, OR 1.05 (95% CI 0.99–1.11) for GH and OR 1.05 (95% CI 0.98–1.12) for MH associated with changing greenness exposure, did not show any apparent differences from the main analyses. If anything, the imputation appeared to slightly weaken the effects, especially among prognostic group GH 1−, where the OR regarding the effect on general health from changing greenness exposure decreased from 1.24 (95% CI 1.01–1.52) to 1.16 (95% CI 0.98–1.37). The prevalence of good GH at baseline increased from 44% to 69% when the less restrictive definition was used. As in the main analyses, results from logistic and ordinal regression analysis for this definition of GH showed weak effects overall, with OR 1.03 (95% CI 0.99–1.08), for average exposure and OR 1.03 (95% CI 0.98–1.08), for changing exposure. However, in contrast to the main analyses, no beneficial effect from increased greenness was seen among subjects with the lowest prognostic of good general health (GH 1−, OR 0.97, 95% CI 0.80–1.17 in the logistic analysis, and a similar result was obtained with ordinal regression).

4. Discussion

4.1. Principal findings

Individuals living in areas with more of the five green qualities had higher likelihood of physiological and psychological wellbeing, but we found only weak evidence for a general beneficial health effect of moving to a neighbourhood with more green qualities. The effect size was small and thus a considerable change of the standardized SGS is required to trigger a noticeable increase in the likelihood of wellbeing. The results indicated that individuals with lower likelihood of having good GH may benefit more than others from an increase in neighbourhood green qualities, but this association was only seen when the restrictive definition of GH was used.

4.2. Strengths and limitations

Our extensive longitudinal survey data allowed for an innovative approach for analysing the effect of changing exposure to greenness triggered by moving using prognostic groups. We eliminated single-source bias by using survey data from separate cohorts for the assessments of green qualities and health status.

Table 4
Associations over time between Scania green score (SGS) and good mental health (MH) for prognostic groups at baseline in 2000 with (1) or without (0) long-term illness and with a likelihood of having good MH below (−) or above (+) median. The presented effect estimates from generalised linear mixed models imply the odds ratio for good MH for each increase of the standardized SGS equal to one standard deviation.

Mental Health			Inter-individual association				Intra-individual effect			
				$SGS_{Average}$[a]				$SGS_{Current} - SGS_{Average}$[b]		
		Prognostic group	*n*[c]	OR	95% CI	*p*-Value	*n* (%)[d]	OR	95% CI	*p*-Value
Long-term illness	Yes	MH 1−	1317	1.00	0.93–1.07	>0.30	476 (36)	1.08	0.93–1.25	>0.30
		MH 1+	1329	1.04	0.97–1.12	0.28	267 (20)	1.05	0.84–1.32	>0.30
	No	MH 0−	3481	1.04	0.99–1.09	0.12	1275 (37)	1.03	0.94–1.13	>0.30
		MH 0+	3317	1.02	0.97–1.08	>0.30	694 (21)	1.19	1.00–1.41	0.05
		Total[e]	9444	1.03	1.00–1.06	0.08	2712 (29)	1.07	1.00–1.14	0.07

[a] Mean SGS during follow-up (year 2000–2005–2010).
[b] Difference between SGS at each survey time point (year 200, 2005 or 2010) and the mean SGS during follow-up.
[c] Number of individuals with complete data in each prognostic group at baseline in 2000.
[d] Number (%) of all individuals with complete data at baseline in 2000 that changed SGS exposure during follow up.
[e] Weighted by the inverse of the standard error of each group-specific estimate.

Thus, exposure misclassification in the present study can be assumed to be non-differential (i.e. independent of disease status), but the consequences of such misclassification may still be unpredictable since the exposure variables used were not binary (Wacholder et al., 1994). The assessment of exposure and health was limited to cross-sectional surveys of the longitudinal cohort which means that reversed causality, i.e. improvement in health leads to the decision to relocate to greener areas rather than vice versa, cannot be ruled out. The participation rates at the follow ups were high but associated with GH and MH at baseline. Such selective participation would result in selection bias if also related to changes in exposure.

In previous cross-sectional studies from the same region, SGS based on the five items has been shown to be associated with objective measures of greenness, neighbourhood satisfaction, physical activity and general health (de Jong et al., 2011, 2012). In future studies, the SGS assessment tool will be extended with three additional dimensions (Grahn, 1991; Stigsdotter et al., 2010) two of which are likely to have restorative properties (Grahn and Stigsdotter, 2010; Pálsdóttir, 2014). Another limitation of the exposure assessment was the large number of areas with no self-reports (which were excluded from the study) or with only a few self-reports available from the independent survey. The ecometrics model shrinks the exposure estimates for areas with few self-reports towards the global mean. These areas were more often found in rural settings and are likely to have more green qualities than average, thus leading to underestimation of neighbourhood greenness. However, only 13% of the participants were residing at baseline in areas with five responders or less. More than two thirds of the participants in our study cohort did not change exposure by moving during follow-up, thereby hampering the statistical power to detect effects of changing greenness exposure. The age difference between non-movers (older) and movers (younger) may be one explanation for the different patterns in the inter-individual and the intra-individual associations with GH noted across the prognostic groups.

A recent reliability analysis based on index raters and their nearest neighbours showed spatial separation between positive assessments and indefinite/missing assessments of neighbourhood greenness (Björk et al., 2014), thus providing support for our decision to assess the number of positive assessments in relation to all respondents in a particular area (including indefinite/missing assessments). However, the same reliability analysis did not provide consistent support for the decision to dichotomise all five items of SGS, which thus may have introduced some additional misclassification of the exposure.

In our study, results in subgroups were not robust to changes in the classification of good GH. The difference in prevalence of good GH in main analysis (44%) and sensitivity analysis (69%) is a plausible explanation for this divergence. Using two questions when defining GH, as was done in the main analyses, is likely to increase specificity but decrease sensitivity. Non-differential misclassification of a binary outcome variable usually yields bias towards the null (Chen et al., 2013), but the exact trade-off between specificity and sensitivity of the outcome classification is hard to assess in settings where no reference standard exists. We used outcome prognostic stratification to study subgroups that may be particularly susceptible to effects of neighbourhood greenness, but this approach may also yield a risk for residual confounding. For ordinary exposure propensity models, stratification into five groups has been shown to account for approximately 90% of the confounding (Austin, 2011). However, our approach of adjusting for the individual difference in prognostic vs. the group average both at baseline and at follow-up can be expected to reduce bias additionally.

4.3. Results in relation to previous studies

Few studies have investigated associations between independent perceptions of green qualities and health in longitudinal settings. A previous cohort study from the US used independent perceptions of neighbourhood resources for physical activity and availability of healthy foods and found clear associations with the risk of type 2 diabetes, also after adjustment for individual-level factors (physical activity and diet) assumed to be part of the causal pathway (Auchincloss et al., 2009). Self-selection into salutogenic neighbourhoods has been suggested as an alternative explanation for such findings (Katz, 2009). In both the present study and in previous cross-sectional studies from the same region (de Jong et al., 2012) individuals living in areas with high numbers of green qualities had the highest likelihood of physiological and psychological wellbeing, but these findings may to an unknown extent also be a consequence of self-selection.

Our results suggest only weak effects on mental health overall of changing exposure to neighbourhood greenness. A recent longitudinal study from urban areas in the UK found a considerable positive effect on mental health from moving to an area with more greenness (Alcock et al., 2014). This study also measured mental health using the GHQ-12 questionnaire but used a measure of total green space coverage. A previous study based on our cohort from the first two occasions (year 2000 and 2005) found that objectively measured green qualities were not clearly associated with GHQ-12 (Annerstedt et al., 2012). The present study indicated a greater benefit of changing exposure to neighbourhood greenness among people with the lowest likelihood of good GH, which is consistent with previous work suggesting that the health benefits of access to green space may depend on socioeconomic status (Mitchell and Popham, 2008). However it has been shown that people living in more deprived areas, though having greater access, use green spaces less than others (Jones et al., 2009). These previous studies used objectively measured greenness, not reflecting human perceptions of the neighbourhood as in our study. It is likely that it is not the amount of greenness as such but rather the perceived quality of the greenness that is most important for wellbeing, and possibly even more so for vulnerable subgroups. It is also conceivable that the different aspects of neighborhood greenness included in SGS may have different associations with wellbeing (de Jong et al., 2012), but this issue was outside the scope of the present investigation.

4.4. Implications and issues for further research

As cities densify, the need to monitor people's access to and use of recreational environments increases. The use of tools to identify and assess the quality of outdoor environments as well as the general well-being of the population should be an important part of public health efforts. Subjective assessment tools, such as the short survey instrument used in the present study, can be a useful complement or alternative to objective measures of outdoor environments.

In the present study, older people were less likely to have moved during the follow-up period. Moving or non-moving is most certainly not a random phenomenon and often depends on factors outside the individual's own control. This implies that those individuals who would gain most from a change of exposure may not have resources or ability to move to more salutogenic environments. Efforts thus need to be undertaken to improve the quality of recreational environments in close proximity to where people live today. When such actions are focused on geographical areas where more vulnerable individuals reside, the positive impact on general health is likely to be more marked.

From a research perspective, it will be important to carefully consider how different needs implied by different groups affect the appropriate study design. Intervention studies in less affluent areas aiming at subgroups that lack abilities to move can be of great importance. Likewise studies specifically focusing on people who do move may reveal interesting new information. Such studies may preferably include a combination of qualitative and quantitative methods. Further, studies of natural experiments in which a population's green qualities changed without an intervention of the environment can be another alternative. Longitudinal studies should use a detailed monitoring of health outcomes as well as of changes in perceived and objectively assessed neighborhood greenness, while at the same time carefully avoiding the risk of single source bias. Studies including registry data to assess the incidence of different diseases in relation to changes in greenness exposure should also be encouraged.

5. Conclusion

Individuals living in areas with more positive green qualities had better wellbeing, but this may to an unknown extent be explained by self-selection. The study provided only weak evidence for beneficial effects of increased neighbourhood greenness triggered by changing residence. It thus seems that the altered life circumstances that often trigger the decision to move are also the key factors that dominate the health consequences of changing residence. However, it cannot be ruled out that subgroups that would benefit from increased neighbourhood greenness also lack abilities to move to such areas.

Authors' contributions

All authors have directly participated either in the planning, execution or analysis of this study. The study was initiated and further developed by HW, JB and LR. The statistical analysis was carried out by HW in cooperation with JB and LR. All authors have revised drafts and contributed to the discussion as well as approved the final version submitted.

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