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Streetscape greenery and health: Stress, social cohesion and physical activity as mediators

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ABSTRACT

Several studies have shown a positive relationship between local greenspace availability and residents' health, which may offer opportunities for health improvement. This study focuses on three mechanisms through which greenery might exert its positive effect on health: stress reduction, stimulating physical activity and facilitating social cohesion. Knowledge on mechanisms helps to identify which type of greenspace is most effective in generating health benefits. In eighty neighbourhoods in four Dutch cities data on quantity and quality of streetscape greenery were collected by observations. Data on self-reported health and proposed mediators were obtained for adults by mail questionnaires (N = 1641). Multilevel regression analyses, controlling for socio-demographic characteristics, revealed that both quantity and quality of streetscape greenery were related to perceived general health, acute health-related complaints, and mental health. Relationships were generally stronger for quality than for quantity. Stress and social cohesion were the strongest mediators. Total physical activity was not a mediator. Physical activity that could be undertaken in the public space (green activity) was, but less so than stress and social cohesion. With all three mediators included in the analysis, complete mediation could statistically be proven in five out of six cases. In these analyses the contribution of green activity was often not significant. The possibility that the effect of green activity is mediated by stress and social cohesion, rather than that it has a direct health effect, is discussed.

INTRODUCTION

Evidence is mounting that greenspace in the residential environment is associated with health. However promising, more detailed knowledge on this association is needed to assess the opportunities it offers for health improvement (Frumkin, 2013). Several studies have shown a positive relationship between local greenspace availability and peoples' health and wellbeing (De Vries et al., 2003, Maas et al., 2006, Maas et al., 2009, Mitchell and Popham, 2007, Mitchell and Popham, 2008, Sugiyama et al., 2008 and Takano et al., 2002). Sometimes no such relationship is observed (see e.g. Richardson and Mitchell, 2010 and Richardson et al., 2012). This may have to do with different operationalizations of greenspace and/or the quality of the greenspace. Two studies found a positive relationship between the (perceived) quality of greenery and health (Agyemang et al., 2007 and Van Dillen et al., 2012), whereas no such relationship was found for yet another operationalization of quality (Björk et al., 2007). Finally, little research has been conducted to identify which processes are responsible for the relationship between nearby greenspace and neighbourhood health, and to what extent (Maas et al., 2009, Maas et al., 2008, Sugiyama et al., 2008 and Van den Berg et al., 2010). Lee and Maheswaran (2011) conclude that while most studies support the view that greenspace has a beneficial health effect, establishing a causal relationship is difficult. Insight in the operating mechanism(s) might help, because it indicates which type of greenery is effective and what type(s) of health benefit(s) are generated (De Vries, 2010). This study builds on Van Dillen et al. (2012), which showed that especially the quantity and quality of streetscape greenery is associated with health, more so than the quantity and quality of nearby green areas. Streetscape greenery includes all kinds of vegetation that give the street a green appearance. This follow-up study investigates to what extent stress, physical activity, and social cohesion mediate the relationship between streetscape greenery and health. Doing so may give insight into which types of greenspace are most effective in generating health benefits, and thereby help to exploit these benefits more fully.

Stress and availability of greenspace

Contact with nature is hypothesised to help people restore from attentional fatigue and reduce stress. This is important because chronic stress negatively affects both physical (Brotman et al., 2007 and Smith et al., 2005) and mental health (Bovier et al., 2004 and Marin et al., 2011). Experimental evidence shows that contact with nature indeed provides restoration from (short term) stress and attentional fatigue (see e.g. Hartig et al., 2003 and Morita et al., 2007). Since it seems to be related to health more clearly, we will focus on stress. Three cross-sectional studies have shown a negative relationship between the perceived availability of local greenspace and stress levels of residents (Grahn and Stigsdotter, 2003, Nielsen and Hansen, 2007 and Stigsdotter et al., 2010). We are not aware of studies addressing local greenspace quality and stress levels.

Physical activity and availability of greenspace

People with much greenspace in their living environment might be more physically active because of this. Higher levels of physical activity contribute to better health (Pate et al., 1995 and Pretty et al., 2007). Empirical support for more greenspace being associated with more total physical activity is mixed. Several studies do find such a relationship (Coombes et al., 2012 and Ellaway et al., 2005), whereas others do not (King et al., 2005). Sometimes even a negative relationship is found (Duncan & Mummery, 2005). For reviews, see Kaczynsky and Henderson (2007) and Lachowycz and Jones (2010). The latter conclude that while the majority of papers found a positive or weak association between greenspace and obesity-related health indicators, findings were inconsistent and varied across studies. Green aspects of the neighbourhood environment are perhaps more likely to affect participation in a subset of activities, namely those that take place in this environment, such as walking for pleasure or transport. Although more common (Li et al., 2005 and Sugiyama et al., 2008), even for this subset of activities not always positive relationships with greenspace availability are observed (e.g. Maas et al., 2008). Note that, when looking at energy expenditure, there is no reason why green physical activity should be more effective than other types of physical activity.

Physical activity and quality of greenspace

As for the quality of the greenery, several studies have shown a more general relationship between the aesthetics or attractiveness of the streetscape and specific types of activity. Attractiveness was positively related to peoples' walking behaviour (Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003), for exercise (Ball, Bauman, Leslie, & Owen, 2001) as well as for leisure (Owen, Humpel, Leslie, Bauman, & Sallis, 2004). Quality aspects of neighbourhood greenspace (such as pleasantness, lack of nuisance, good paths) have also been associated with more walking time (Sugiyama & Ward Thompson, 2008). Björk et al. (2007) did find a relationship between how many out of five green recreational values (serene, wild, lush, spacious, and culture) were present near one's residence and physical activity (but not health). In another study, with a different operationalization of quality, no relationship was found (Van Lenthe, Brug, & Mackenbach, 2005).

Finally, two studies paid attention to greenspace availability as well as quality. Hillsdon, Panter, Foster and Jones (2006) looked at distance, size and quality of urban greenspace, and observed no relationships with recreational physical activity. On the other hand, Giles-Corti et al. (2005) also took distance, size and attractiveness of public open spaces simultaneously into account, and observed positive relationships between attractiveness and walking.

Social cohesion and availability of greenspace

Social cohesion has been defined in many ways. In this study, we use it as an equivalent of sense of community, with a focus on trust, shared norms and values, positive and friendly relationships, and feelings of being accepted and belonging (Forrest & Kearns, 2001). Previous research has shown a positive relationship between social cohesion and health (Echeverria et al., 2008 and Rios et al., 2012). In two studies neighbourhood greenness was related to social cohesion (Maas et al., 2009 and Sugiyama et al., 2008). In both studies, social cohesion itself was positively

associated with health and wellbeing. We are not aware of studies explicitly addressing the relationship between quality of local greenspace and social cohesion. To what extent may these three mechanisms explain the relationship between greenspace and health? Sugiyama et al. (2008) found that walking for recreation helped explain the relationship between perceived neighbourhood greenness and physical health, while the somewhat stronger relationship between perceived neighbourhood greenness and mental health was partially accounted for by walking for recreation and social cohesion. They hypothesised that the residual relationship between greenness and mental health might be due to the restorative effects of natural environments, an aspect that was not included in their study. The present study extends the work of Sugiyama et al. (2008); to begin, we include stress as a possible mediator. Moreover, we not only look at physical activity that might be associated with nearby nature, but also at overall physical activity. Finally, we use more objective information on the quantity and quality of greenery in the neighbourhood, rather than the perceptions by residents. Giles-Corti and Donovan (2002) highlight the importance of using objective measures to better understand the relationships between environments and behaviours.

In summary, we hypothesise that residents in neighbourhoods with more and/or higher quality streetscape greenery experience less stress, more social cohesion, and spend more time on (green) physical activity. Our second set of hypotheses is that stress is negatively related to health, and (feelings of) social cohesion and (green) physical activity are positively related to health. Finally, we expect that stress, social cohesion and (green) physical activity will mediate the relationship between quantity and quality of greenery in urban neighbourhoods and health to a significant extent.

METHODS

Study population

Four Dutch cities (Utrecht, Rotterdam, Arnhem, Den Bosch) were chosen with comparable levels of urbanity and at least 125,000 inhabitants. Within each city 20 neighbourhoods were selected. Neighbourhoods were defined as administrative units, having 2200 residents on average. The average quantity of public green area (i.e., square metres available per residence within a distance of 500 m) was used to select ten more and ten less green neighbourhoods within each city to ensure variation in the amount of green area. (However, this is not directly relevant for streetscape greenery.) During this selection we tried to exclude neighbourhoods with very peculiar or extreme socioeconomic profiles to keep the sample as homogeneous as possible in this respect. Profiles were assessed based on neighbourhood-level data available at Statistics Netherlands.

Observation of streetscape greenery

Within each neighbourhood four streets were selected by placing four adjacent circles with a radius of 500 m on the map of the neighbourhood and picking the street in the centre of each circle. Observers were instructed to stand in front of a specified address and then assess the street. For this purpose an audit tool was developed. Quantity was assessed with one item running from (1) the street does not make a very green impression to (5) the street makes a very green impression.

'Green' was broadly defined as all types of visible vegetation, ranging from flower boxes and green façades to a view of woodland. Quality of streetscape greenery was assessed with five items: variation, maintenance, orderly arrangement, absence of litter, and general impression. All quality items were scored on 5-point scales. In April 2007, 80 neighbourhoods were visited, and 320 streets were observed. Sixteen neighbourhoods were visited by a second observer to assess the inter-rater reliability of the audit tool. The quality items intercorrelated considerably

(Cronbach's $\alpha = 0.75$). Inter-rater consensus was calculated by dividing the number of agreements by the maximum possible number of agreements. Scores were defined to agree when they differed by no more than one scale point. Agreement per item ranged from 76% to 98%. Quality items were averaged to get a score per street. Results per street were averaged to get quantity and quality scores for the neighbourhood as a whole. Quantity and quality correlated $r = 0.76$. See Van Dillen et al. (2012) for more information on the audit instrument.

Questionnaire

One hundred residents per neighbourhood were randomly selected out of a personal mailing addresses database of a commercial agency. In June 2007, 8000 residents received a personal letter and a mail questionnaire. It was also possible to fill in the questionnaire on the Internet. After two weeks, all residents received a reminder card. It took about 30 min to fill out the questionnaire. Respondents could win a ticket in a national lottery. Altogether 1553 respondents returned the mail questionnaire, while 208 respondents filled out the internet questionnaire. After removing 94 questionnaires returned empty and 26 questionnaires with missing values on any variable in any of the analyses, 1641 questionnaires remained. The response rate was 22% (range 7–46). Characteristics of the study population are shown in Table 1. Non-western ethnic minorities were clearly underrepresented, whereas older age groups were somewhat overrepresented (not in table, see Van Dillen et al., 2012).

[TABLE 1.]

Health indicators

Respondents had to assess their perceived general health on a five-point scale from "bad" to "excellent". This indicator originates from the Short-Form 36 (SF-36) health survey and has been used in many studies (Ware et al., 1995). In addition, it was asked whether one suffered from any of a list of 37 acute health-related complaints in the last 14 days (Foets & Van der Velden, 1990). The score was the number of affirmed complaints. Third, the Mental Health Inventory (MHI-5) was used, consisting of five items. Scores were transformed into a scale from 0 to 100 ($\alpha = 0.81$), with higher scores indicating better mental health (Ware et al., 1995).

Indicator for stress

Stress was measured by the short version of the Perceived Stress Scale developed by Cohen, Kamarck and Mermelstein (1983), translated into Dutch (4 items, $\alpha = 0.65$). The number of life events in the past year was used as a covariate, because of its influence on stress (Ormel & Koeter, 1985) (range: 0–17).

Indicator for social cohesion

We developed a five-point scale ($\alpha = 0.91$) for social cohesion based on five statements on social cohesion (Sampson, Raudenbush, & Earls, 1997), four on social quality (Intomart, 2001) and four on social wellbeing (Völker, Flap, & Lindenberg, 2007). Such examples include: “People around here are willing to help their neighbours”, “People in this neighbourhood hardly know each other”, “I feel safe in this neighbourhood” (see Appendix A for full list of statements). Having children living at home was used as a covariate, since it was significantly associated with social cohesion.

Indicator(s) for physical activity

Physical activity was assessed by the easy to administer Short Questionnaire to Assess Health-enhancing physical activity (SQUASH) (Wendel-Vos, Schuit, Saris, & Kromhout, 2002). Besides overall physical activity, we focused on activities that could be performed in green outdoor environments, namely walking for transport (from/to work or school), cycling for transport, walking for leisure, cycling for leisure, and gardening. Scores for frequency (number of days per week) and duration (average time in minutes per day) were multiplied per activity and then summed to obtain total scores for (green) physical activity.

Socio-demographic characteristics

Gender and age were included as demographic variables. Socio-economic status was assessed by highest level of completed education (seven categories) and household income (three categories: monthly net income below 1300 Euro, between 1300 and 1900 Euro, above 1900 Euro). To correct for life-style factors, we included smoking and excessive drinking (six or more glasses of alcohol on at least three days per week during the last twelve months) in our models. The same set of covariates was used in all models, regardless of whether they contributed significantly at any stage or not.

Statistical analysis

We used multilevel analysis to investigate the mechanisms behind the relationship between urban greenery and health. Two levels were included: individual and neighbourhood. For most dependent variables a multilevel linear regression analysis was performed. For acute health-related complaints multilevel regression with (extra) Poisson method was used because of the non-normal distribution (count data). Both

physical activity indicators were logarithmically transformed ($\ln(x + 1)$), because of their strongly skewed distribution.

Testing for mediation presumes a causal chain of events. The analyses cannot actually prove this causality, but they can show whether the data are in line with the assumed chain of events or not. In our analyses we followed the procedure for establishing mediation proposed by Baron and Kenny (1986). The four phases in this procedure form the subheadings of the results section. Whenever possible we also tested whether the regression model as a whole still improved when the greenery indicators are introduced after the mediator had already been included. If mediation is not complete the more distal indicators may still have additional predictive value. Analyses were performed with SPSS (version 15) and MLwiN (version 2).

RESULTS

Phase 1: are greenery and health related?

The basic models for the health indicators, containing all the covariates we corrected for, are shown in Table 2 (step 1). The health indicators are interrelated, but not excessively so: from $r = 0.35$ for perceived general health and mental health to $r = -0.50$ for acute health-related complaints and mental health.

[TABLE 2.]

Subsequently we included quantity and quality of streetscape greenery in the model, one at the time (Table 2, steps 2 and 3). Residents living in neighbourhoods with more streetscape greenery perceived their own health as better, experienced less acute health-related complaints, and had a better mental health status than residents living in neighbourhoods with less streetscape greenery. When the quality of the streetscape greenery was added, this improved the model even further, while it made the quantity information redundant. So, for all three health indicators there is an effect to be mediated to begin with. Earlier we already checked whether quantity and quality interacted, which was not the case for all three health indicators (Van Dillen et al., 2012).

Phase 2: is greenery related to the possible mediator(s)?

In this phase the mediators are the dependent variables. The first model was for stress, adjusting for the same covariates as in the models for health. A similar analysis was performed for social cohesion. For physical activity two models were tested: one for overall physical activity and one for green activity (Table 3). The two variables correlated $r = 0.56$.

[TABLE 3.]

Stress was related to quantity as well as to quality of streetscape greenery separately. Although quality was more strongly related to stress than quantity, it did not have significantly added predictive value once quantity was already known. Social cohesion was also clearly related to both quantity and quality of streetscape greenery

separately. Quality did have added predictive value, and made quantity redundant. Quantity of streetscape greenery had no predictive value with regard to total physical activity, nor had its quality. For the subset of green activity only quality had predictive value.

Phases 3 & 4: possible mediators related to health and contribution of greenery diminished?

In none of analyses for health quantity of streetscape greenery contributed significantly when quality of streetscape greenery was also included in the model (Table 2, step 3). Nevertheless, for reasons to be presented later, we will look at quantity and quality separately. Phases 3 and 4 will not be performed for total physical activity, since it was not related to any of the greenery indicators. Green activity will be included, although there is only an effect of greenery quality on this mediator. Phases 3 and 4 are reported by mediator.

When stress is included in the model, together with either quantity or quality of greenery, it shows a highly significant parameter for all three health indicators (Table 4). So stress also satisfies the last requirement for mediation to occur. But to what extent does it? Quantity of greenery still contributes to perceived general health and acute health-related complaints, but not to mental health. In the latter case the regression model as a whole also does not improve when quantity is added to the model already including stress. Quality still contributes for all three health indicators. So only in the case of the effect of quantity of greenery on mental health complete mediation by stress has taken place, i.e., the greenery indicator no longer had added predictive value.

[TABLE 4.]

Social cohesion is also highly significantly related to the three health indicators, regardless of whether quantity or quality of greenery is included in the model. So, also social cohesion may function as a mediator in all three cases. As for quantity of greenery, only for perceived general health its parameter is significant (and the model improves significantly). For acute health-related complaints and mental health complete mediation of the effect of quantity of streetscape greenery by social cohesion has taken place, in the sense that the parameter for quantity was not significant anymore. The parameter for quality of streetscape greenery is still significant for all three health indicators (and adding quality improves the model as a whole). For quality no complete mediation has taken place by social cohesion. Green activity is also significantly related to all three health indicators, whether quantity or quality is included, although less strongly so in the case of acute health-related complaints. The parameter for quality still is significant for all three health indicators. Quality also improves the model when green activity is already included. So no complete mediation by green activity could be shown in any of the three analyses. For quantity mediation was not to be expected to begin with, since this characteristic was not related to green activity. Finally we combined all mediators in one analysis. The three mediators are interrelated, but only weakly so. The association between stress and social cohesion was significant ($r = -0.14$), as well as that between stress and green activity

($r = -0.11$) and social cohesion and green activity ($r = 0.11$). With all three mediators included, complete mediation occurs in five out of six cases (Table 5). Quality still has a direct effect on perceived general health. For acute health-related complaints and mental health, green activity no longer contributes significantly.

[TABLE 5.]

The effect of quantity of streetscape greenery on mental health appeared to be completely mediated by stress as well as by social cohesion. To get a better idea of which part of the total effect of the greenery indicators was mediated by the different mediators, we calculated the difference between the parameter for the indicator without the mediator(s) and that with the mediator(s) included in the multilevel multiple regression equation (B and B'). The indirect effect is expressed as a percentage of the parameter size in the without situation: $100*(B - B')/B$ (Fig. 1).

[FIGURE 1]

The percentages are quite similar for quantity and quality of streetscape greenery. Green activity is a less strong mediator. For mental health the mediation by stress is about twice that for perceived general health. For perceived general health the mediation by social cohesion is somewhat lower than for either acute health-related complaints or mental health. Finally, when all three mediators are included simultaneously the indirect effect becomes considerably higher. It is at least 80% of the sum of the indirect effects for the three mediators separately, consistent with earlier findings that interrelations between mediators are weak.

DISCUSSION

Relationship between greenery aspects and possible mediators

The study confirmed relationships between quantity and quality of streetscape greenery on one hand and stress and social cohesion on the other hand. For green activity only a relationship with the quality was observed, while for total physical activity no relationship with either quantity or quality of greenery could be shown. This latter result is not unprecedented. It is unclear why the different studies produce different results. Usually there are simultaneously occurring differences in the design of the studies. For example, environmental characteristics as well as physical activity are often measured in different ways. Leslie, Sugiyama, Ierodionou, and Kremer (2010) suggest that objective and perceived measures may be capturing quite different aspects of neighbourhood greenness. But even if we limit ourselves to objective measures, results depend on exactly what is taken into account when it comes to greenspace (Fan et al., 2011 and Van Dillen et al., 2012).

Relationship between possible mediators and health

Relationships between all three possible mediators and all three health indicators were shown, confirming their mediating capabilities in this respect. For green

activity this is somewhat remarkable, since it only is a part of the total physical activity. Usually mainly total physical activity level (energy expenditure) is presumed to affect health, more or less regardless of the shape or form the activity comes in. On the other hand, there might be something especially beneficial about activities performed in a green environment (see Thompson Coon et al., 2011).

Relationship between greenery, mediators and health

Especially stress and social cohesion were important mediators. The fact that green activity became redundant when stress and social cohesion were also included in the analysis, suggests that this contribution itself may be mediated by stress and/or social cohesion. It may not be the amount of energy expenditure that the activity brings along that generates the health benefits, but the stress-reducing qualities of the environment in which the activity takes place, and/or the social cohesion that is facilitated by the activity. The quantity and quality of local greenery may be more important because they influence the place where people spend their leisure rather than the (overall) level of physical activity (see, also Hartig, 2008).

Our results deviate from Sugiyama et al. (2008), with walking for health as the most important mediator. In our study walking for recreation is a part of green activity, which was the weakest mediator. On the other hand our conclusion is in line with that by Maas et al. (2008): they also concluded that physical activity was not an important mediator of the effect of the quantity of nearby greenspace on perceived general health.

With regard to the importance of social cohesion as a mediator, we come to the same positive conclusion as Sugiyama et al. (2008). Also Maas et al. (2009) point in this direction: in their study loneliness and perceived shortage of social support completely mediated the effect of the amount of greenspace on mental health. This clearly emerging role of social cohesion is remarkable, since it is the least studied of the three mechanisms thus far. It is also not uncontested: Fan et al. (2011) concluded that social support is negatively influenced by the neighbourhood vegetation level.

Quality versus quantity of streetscape greenery

Although quantity and quality of streetscape greenery were clearly related, quality still had predictive value with quantity already in the equation. Moreover, quality information made quantity information redundant. Nevertheless, we continued to look at both quantity and quality of streetscape greenery. Quality of streetscape greenery may also be considered highly indicative of the quality or attractiveness of the physical appearance of the neighbourhood as a whole, including its non-green parts. This attractiveness may, by way of residential satisfaction, affect wellbeing and (mental) health (Leslie and Cerin, 2008 and Phillips et al., 2005). If so, the results may not be very specific for the greenery within the neighbourhood. But, although relations are stronger for quality, the pattern of results for quantity is quite similar, suggesting that green elements in the neighbourhood do have beneficial health effects.

Nevertheless, greenery might do 'nothing else' than make the neighbourhood more attractive. The issue is whether or not green elements have some additional, special effect. As for social contacts and physical activity, these underlying mechanisms do not presuppose a special function of streetscape greenery beyond making the

neighbourhood more attractive. With regard to stress reduction, it can be argued that natural elements have better stress reducing qualities than built-up or hardened surfaces. However, Karmanov and Hamel (2008) claim that even for stress reduction it may be the attractiveness of the environment that is important, and not its greenness per se (see also Pretty, Peacock, Sellens, & Griffin, 2005).

Strengths and limitations

As for limitations, no firm conclusions can be drawn about causality, because the study is cross-sectional. We used self-reported measures for physical activity, social cohesion, stress as well as health. Social cohesion, stress and health to a large degree made use of a similar answering format, possibly leading to the same method and same source bias. Such a bias may lead to overestimating of the strength of relationships. However, overall the results were quite similar for acute health-related complaints and perceived general health, while these two measures differed considerably in answering format. This suggests that the same method part of such a bias was not large. For perceived stress and mental health there is also the issue of a potential conceptual overlap. Although it is not uncommon to see stress as a risk factor for mental health (see e.g. Marin et al., 2011), some authors are more inclined to define perceived stress as a dimension of mental health (see e.g. Aszatalos et al., 2009).

With regard to physical activity there is the issue of the unreliability of measure. Kwak, Kremers, Brug and Van Baak (2007) conclude that the SQUASH has practical advantages in terms of convenience of administration, but that its usefulness in estimating physical activity is limited. This may have lowered the strength of the relationships with both greenery and health indicators. Furthermore, there is also the issue of a low response rate, especially in some neighbourhoods. This limits our ability to generalise our results, despite statistical corrections for several socio-demographic characteristics, especially when it comes to non-western ethnic minorities. These minorities seem to perceive nature differently (Buijs, Elands, & Langers, 2009), which may affect how contact with nature influences their health. Low response rates also lower the power of the analyses, making it more difficult to find relationships. However, they are not likely to have affected the outcomes otherwise (see Van Dillen et al., 2012).

As for strengths, this is one of the first studies to examine the mechanisms through which nearby greenery exert a positive effect on health. In contrast to other studies (Maas et al., 2008 and Maas et al., 2009), we focused not only on the availability of greenery, but also on its quality and obtained data on the quantity and quality of greenery through observations in the field. Because data on greenery and on mechanisms and health were derived from different sources, there is no single source bias as far as the greenery indicators are involved. Finally, in contrast to other studies (Maas et al., 2008, Maas et al., 2009 and Sugiyama et al., 2008), we explicitly included three different mediators altogether in our model to explain health, with stress being one of them. If the relative importance of stress reduction and enhancing social cohesion is confirmed in other studies, a next step is identifying the type of greenspace that is most likely to facilitate these mechanisms (De Vries, 2010). We hope that this study stimulates research along these lines, and eventually lack of knowledge will no longer prevent the possibilities that contact with nature offers to improve human health of being used to their fullest potential.

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APPENDIX A. SUPPLEMENTARY DATA

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TABLES AND FIGURES

Table 1

Socio-demographic characteristics, mediating variables and health indicators for the study population ($N = 1641$), and greenspace indicators for neighbourhoods ($n = 80$).

Socio-demographic characteristics	
Gender, % men	49%
Age, mean (sd)	51 (16)
Education, % high	52%
Income, % high	48%
Life events (number, higher = more), mean (sd)	1.14 (1.35)
Having children living at home, %	32%
Smoker, %	22%
Excessive drinker, %	4%
Streetscape greenery indicators ($n = 80$)	
Quantity (1–5, higher = more), mean (sd)	3.10 (0.84)
Quality (1–5, higher = better), mean (sd)	3.42 (0.44)
Mediating variables	
Stress (1–5, higher = more), mean (sd)	3.76 (2.56)
Social cohesion (1–5, higher = more), mean (sd)	3.43 (0.60)
Total physical activity (minutes per week), mean (sd)	2075 (1486)
LN total physical activity + 1, mean (sd)	7.22 (1.35)
Green activity, mean (sd)	483 (538)
LN green activity + 1, mean (sd)	5.46 (1.71)
Health indicators	
Perceived general health (1–5, higher = better), mean (sd)	3.09 (0.81)
Acute health-related complaints (number, higher = more), mean (sd)	4.61 (3.80)
Mental health status (0–100, higher = better), mean (sd)	76.76 (14.32)

Table 2
Regression of self-reported health indicators on the quantity and quality of streetscape greenery ($N = 1641$).

	Perceived general health [1–5]	Acute health-related complaints [0–37] ^a	Mental health status [0–100]
Step 1: basic model			
Intercept	2.935(0.126)***	1.973(0.125)***	67.893(2.277)***
Gender (men = 0)	–0.070(0.039)	0.205(0.040)***	–2.706(0.699)***
Age	–0.006(0.001)***	–0.002(0.001)*	0.076(0.024)**
Education level	0.056(0.012)***	–0.041(0.012)***	0.307(0.224)
Income	0.130(0.032)***	–0.170(0.030)***	3.166(0.569)***
Life events	–0.085(0.014)***	0.100(0.011)***	–2.165(0.248)***
Having children living at home	0.005(0.044)	0.065(0.044)	–0.724(0.779)
Smoker	–0.071(0.046)	0.011(0.045)	–0.215(0.817)
Excessive drinker	–0.119(0.100)	0.102(0.097)	–3.971(1.770)*
Step 2: adding quantity to step 1			
Quantity of greenery	0.068(0.023)** &&	–0.066(0.025)**	1.220(0.438)** &&
Step 3: adding quality to step 2			
Quantity of greenery	0.007(0.036)	–0.004(0.038)	–0.061(0.0662)
Quality of greenery	0.153(0.069)* &	–0.155(0.073)*	3.231(1.274)* &

*: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$, significance of parameters.

&: $p \leq 0.05$; &&: $p \leq 0.01$, significance of model improvement.

NB: parameters for gender, age, education level, income, life events, having children living at home, smoker, and excessive drinker for models in step 2 and 3 are not presented.

^a Poisson model: parameter values for $\ln(\pi)$; no deviance statistic available for model as a whole.

Table 3
Regression analysis of possible mediators on quantity and/or quality of streetscape greenery ($N = 1641$).

	Stress [0–16]	Social cohesion [1–5]	Total physical activity [0–9.4] ^a	Green activity [0–8.8] ^a
Step 2a: adding quantity to model at step 1^b				
Quantity of greenery	–0.154(0.074)* &	0.139(0.034)*** &&&	0.074(0.043)	0.093(0.060)
Step 2b: adding quality to model at step 1				
Quality of greenery	–0.381(0.142)** &&	0.339(0.061)*** &&&	0.112(0.084)	0.305(0.112)** &&
Step 3: adding quality to model at step 2a				
Quantity of greenery	–0.006(0.115)	0.005(0.049)	0.060(0.067)	–0.068(0.090)
Quality of greenery	–0.372(0.222)	0.332(0.093)*** &&&	0.034(0.129)	0.405(0.173)* &

*: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$, significance of parameters.

&: $p \leq 0.05$; &&: $p \leq 0.01$; &&&: $p \leq 0.001$, significance of model improvement.

^a Logarithm of original values: $\ln(x + 1)$.

^b Variables included in the basic model (step 1) are: gender, age, education level, income, life events, having children living at home, smoker, and excessive drinker. Basic model not presented.

Table 4
Regression of self-reported health indicators on a mediator and observed quantity or quality of streetscape greenery ($N = 1641$).^a

	Perceived general health [1–5]	Acute health-related complaints [0–37] ^b	Mental health status [0–100]
Stress as mediator, and quantity of streetscape greenery			
Stress	–0.089(0.007)***	0.089(0.007)***	–3.240(0.111)***
Quantity of greenery	0.054(0.022)* &	–0.050(0.023)*	0.684(0.377)
Stress as mediator, and quality of streetscape greenery			
Stress	–0.088(0.007)***	0.088(0.007)***	–3.232(0.111)***
Quality of greenery	0.130(0.043)** &&	–0.123(0.045)**	1.869(0.710)** &
Social cohesion as mediator, and quantity of streetscape greenery			
Social cohesion	0.150(0.033)***	–0.176(0.032)***	3.614(0.589)***
Quantity of greenery	0.052(0.023)* &	–0.044(0.023)	0.829(0.428)
Social cohesion as mediator, and quality of streetscape greenery			
Social cohesion	0.144(0.033)***	–0.170(0.032)***	3.478(0.591)***
Quality of greenery	0.126(0.045)** &&	–0.111(0.046)*	2.220(0.813)** &&
Green activity as mediator, and quantity of streetscape greenery			
Green activity (ln)	0.059(0.011)***	–0.021(0.010)*	0.708(0.196)***
Quantity of greenery	0.062(0.023)** &&	–0.063(0.025)*	1.151(0.440)** &
Green activity as mediator, and quality of streetscape greenery			
Green activity (ln)	0.058(0.011)***	–0.020(0.010)*	0.679(0.196)***
Quality of greenery	0.146(0.044)*** &&&	–0.154(0.047)**	2.936(0.825)*** &&&

*: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$, significance of parameters.

&: $p \leq 0.05$; &&: $p \leq 0.01$; &&&: $p \leq 0.001$, significance of model improvement when streetscape greenery indicator is added after mediator is already included (step 3 model compared to step 2).

^a Variables included in the basic model (step 1) are: gender, age, education level, income, life events, having children living at home, smoker, and excessive drinker. In step 2 the mediator is added, while in step 3 the streetscape greenery indicator is. Basic model and model at step 2 not presented.

^b Poisson model: parameter values for $\ln(\pi)$; no deviance statistic available for model as a whole.

Table 5
Regression of three self-reported health indicators on all three mediators simultaneously and the observed quantity or quality of streetscape greenery: step 3 results for mediators and greenery indicators ($N = 1641$).^a

	Perceived general health [1–5]	Acute health-related complaints [0–37] ^b	Mental health status [0–100]
Quantity of streetscape greenery			
Stress	–0.084(0.007)***	0.086(0.007)***	–3.185(0.110)***
Social cohesion	0.112(0.032)***	–0.143(0.031)***	2.543(0.485)***
Green activity (ln)	0.043(0.011)***	–0.004(0.010)	0.154(0.160)
Quantity of greenery	0.039(0.022)	–0.033(0.022)	0.397(0.370)
Quality of streetscape greenery			
Stress	–0.083(0.007)***	0.086(0.007)***	–3.182(0.110)***
Social cohesion	0.108(0.032)***	–0.138(0.031)***	2.474(0.487)***
Green activity (ln)	0.043(0.011)***	–0.004(0.010)	0.146(0.160)
Quality of greenery	0.090(0.043)* &	–0.082(0.043)	1.164(0.708)

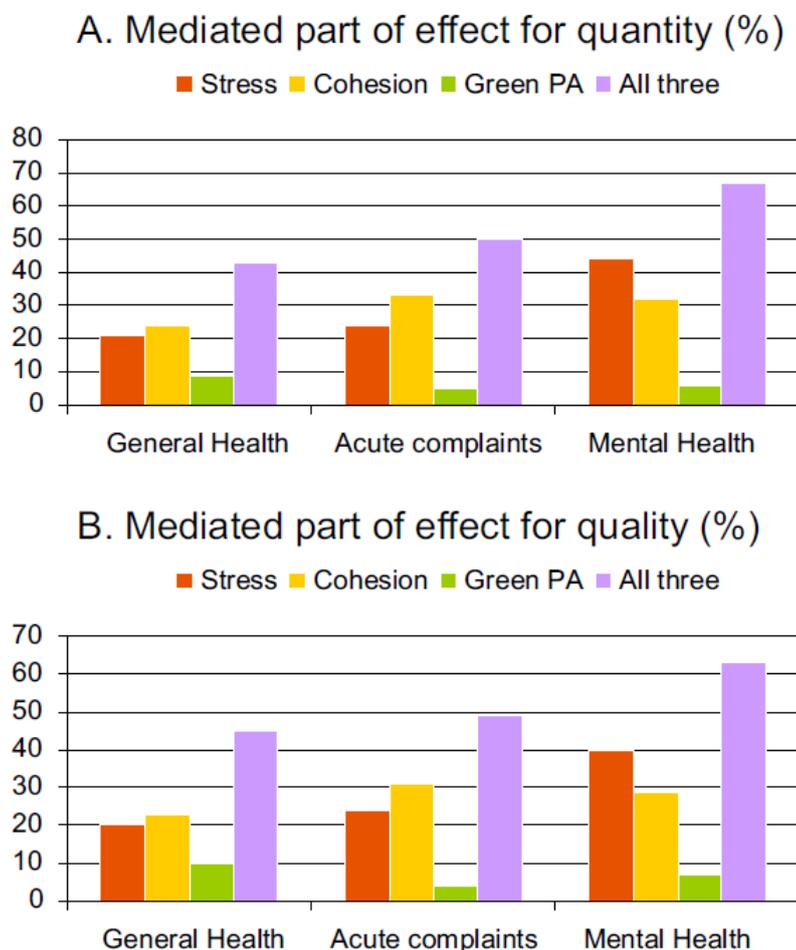
*: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$, significance of parameters.

&: $p \leq 0.05$; &&: $p \leq 0.01$; &&&: $p \leq 0.001$, significance of model improvement when streetscape greenery indicator is added after mediators are already included (step 3 model compared to step 2).

^a Variables included in the basic model (step 1) are: gender, age, education level, income, life events, having children living at home, smoker, and excessive drinker. In step 2 the three mediators are added, while in step 3 the streetscape greenery indicator is. Basic model and model at step 2 not presented.

^b Poisson model: parameter values for $\ln(\pi)$; no deviance statistic available for model as a whole.

Fig. 1. Indirect effect on health indicators as percentage of total effect of quantity (A) and quality (B) of streetscape greenery respectively for the three mediators separately and combined.



APPENDIX 1

Supplementary material: social cohesion scale.

Sampson et al. (1997): social cohesion and trust

1. People around here are willing to help their neighbours
2. This is a close-knit neighbourhood
3. People in this neighbourhood can be trusted

4. People in this neighbourhood generally don't get along with each other (reverse coded)

5. People in this neighbourhood do not share the same values (reverse coded)

Intomart (2001): social quality (translated from Dutch by us)

6. People in this neighbourhood deal with each other in a pleasant way

7. I feel at home with the people living in this neighbourhood

8. I live in a friendly neighbourhood with a lot of togetherness

9. People in this neighbourhood hardly know each other (reverse coded)

Völker et al. (2007): social wellbeing (translated from Dutch by original authors)

10. There are a lot of things going on in this neighbourhood.

11. I feel safe in this neighbourhood.

12. The contacts in this neighbourhood are generally good.

13. I enjoy respect in this neighbourhood.