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DOI
10.1016/j.healthplace.2019.102163

Publication date
2019

Document Version
Final published version

Published in
Health & Place

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Link to publication

Citation for published version (APA):
Weeland, J., Laceulle, O. M., Nederhof, E., Overbeek, G., & Reijneveld, S. A. (2019). The greener the better? Does neighborhood greenness buffer the effects of stressful life events on externalizing behavior in late adolescence? *Health & Place*, *58*, [102163]. https://doi.org/10.1016/j.healthplace.2019.102163

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Download date:25 May 2022

Health and Place 58 (2019) 102163

Contents lists available at ScienceDirect

Health & Place

journal homepage: www.elsevier.com/locate/healthplace

The greener the better? Does neighborhood greenness buffer the effects of stressful life events on externalizing behavior in late adolescence?

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ARTICLE INFO

Keywords:
Externalizing behavior
Mediation
Neighborhood greenness
RSA
Stressful life events

ABSTRACT

We tested whether neighborhood greenness is a promotive and/or a protective factor in the development of adolescent externalizing behavior problems and explored a possible mechanism of its effects via respiratory sinus arrhythmia (RSA) recovery after stress. Data from a longitudinal multi-method study on adolescents ($N = 715$) was used. Result showed that neighborhood greenness was neither a promotive nor a protective factor. However, adolescents who reported more stressful life events showed more externalizing behavior and –contrary to our expectation– this effect was stronger for adolescents who grew up in *greener* neighborhoods (vs. less green neighborhoods).

Over half of all children and adolescents worldwide grow up in cities, and the urban population is ever growing (UNICEF, 2016). Certain aspects of urban neighborhoods, such as low social control, area deprivation, constant arousal, and lack of recreational (green) space, might negatively impact the development of children and adolescents (Christain et al., 2015; Elgar et al., 2003; Legrand et al., 2008; Reijneveld et al., 2010). However, possible positive or promotive neighborhood factors have been largely understudied (for a review see Brumley and Jaffee, 2016). Specifically, there are strong indications that high “neighborhood greenness” (overall vegetation of, and/or access to public natural areas such as parks, in the residential area) is associated with better mental health outcomes in general (Gascon et al., 2015), and with less externalizing problems (maladaptive behaviors directed toward an individual's environment), such as aggressive and rule-breaking, behavior, in particular (e.g., Wells and Evans, 2003; Flouri et al., 2014; Markevych et al., 2014; Younan et al., 2016).

Neighborhood greenness might be a largely overlooked positive neighborhood factor in the development of externalizing behavior. For example, there is evidence that an increase in trees in the neighborhood is related to a decrease in violent crimes (Burley, 2018); access to gardens, parks and playgrounds is related to fewer child conduct, peer and hyperactivity problems (Flouri et al., 2014); and that neighborhood green spaces reduce, both short- and long-term, verbal and non-verbal aggressive behaviors in adolescents (e.g., fighting, destroying things, arguing) (Younan et al., 2016). Adolescence, the phase of life stretching between childhood and adulthood (roughly between the age of 10 and 24 years) encompassing elements of neurocognitive maturation and major social role transitions, is a critical time for the development of externalizing problems (Dahl, 2004; Sawyer et al., 2018). Moreover, these problems have been shown to predict problems later in life, negatively affecting individual wellbeing as well as society at large (e.g., Scott et al., 2001 Von Stumm et al., 2011). However, most studies on neighborhood greenness focus on either children or adults (see Gascon et al., 2015). Of the 28 studies on this topic found by Gascon et al. (2015) only 6 studies included adolescent participants, and none of these studies tested the effects of neighborhood greenness specifically in adolescents. This is important since age differences in the effects of neighborhood greenness have been previously found and findings in other age groups may not generalize to adolescents (e.g., Barton and Pretty, 2010; Bos et al., 2016). In order to implement findings on possible positive effects of neighborhood greenness in adolescent populations (e.g., prevention efforts or public health policy) we thus need studies in this specific age group.

Moreover, the relatively few previous studies on neighborhood greenness and adolescent behavior have important limitations. First of all, the effects of neighborhood greenness on externalizing behavior

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https://doi.org/10.1016/j.healthplace.2019.102163
Received 16 December 2018; Received in revised form 4 July 2019; Accepted 8 July 2019
Available online 22 July 2019
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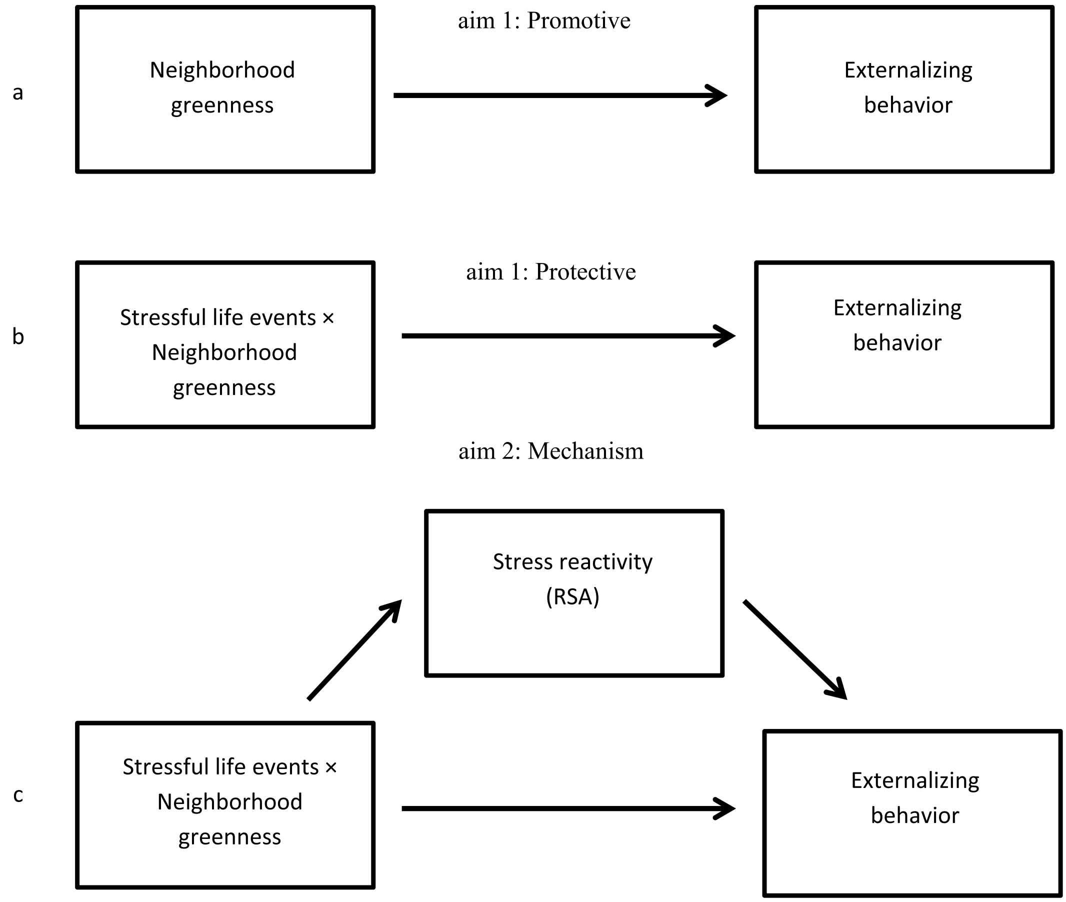

Fig. 1. Visual Diagram of the Tested Model: Path a is The Direct Effect of Neighborhood Greenness on Externalizing Behavior (promotive effect); Path b is The Interaction Effect of Neighborhood Greenness and Stressful Life Events on Externalizing Behavior (protective effect); Path c is the Mediation Effect in Which The Interaction Effect of Neighborhood Greenness and Stressful Life Events has an Indirect Effect on Externalizing Behavior via Stress Reactivity (Explaining Mechanism).

might be intertwined with other neighborhood (specifically urbanization) and family (specifically socio-economic status (SES)) related predictors of this behavior (see Leventhal and Brooks-Gunn, 2000). For example, neighborhood greenness predicts less emotional problems in children, specifically in poor urban families (Flouri et al., 2014). Not all studies control for possible confounding effects of other, to neighborhood greenness related, predictors of externalizing behavior. In order to assess the unique effects of neighborhood greenness it is therefore important to disentangle these different predictors.

Second, most studies only assess direct associations between greenness and behavior, making it unclear whether neighborhood greenness is a promotive (i.e., a direct effect) or a protective factor (i.e., interacting with risk factors) (Brumley and Jaffee, 2016). Third, and most important, we know little about how neighborhood greenness might buffer the effects of risk factors on the development of adolescent externalizing problems. How does it work? Specifically the neurobehavioral benefits of neighborhood greenness in adolescents remain unclear (Younan et al., 2016). The stress recovery hypothesis, building on the Restorative Environment Theory (RET) (Kaplan and Talbot, 1983) and the Stress Reduction Theory (SRT) (Ulrich et al., 1991), states that natural environments (vs. urban environments) have restorative qualities which promote psychophysiological stress recovery (for a review see Berto, 2014). Compared to urban environments natural environments might include fewer stimuli that evoke automatic attention, arousal, and fight-or-flight responses, such as traffic, crowds, noise, and unfamiliar and/or angry faces (Evans, 2006). These environments might thus demand less of our stress response system, leaving room for restoration, and buffer against the effects of stress related risk factors. However, the stress recovery hypothesis has seldom been directly tested as possible mechanism underlying the effects of neighborhood greenness.

An important source of stress during adolescence are negative life events (e.g., divorce or separation of parents), and specifically an aggregation of these events has detrimental effects on the behavior development of adolescents (for a meta-analysis see March-Llanes et al., 2017). This might be because stressful life events deplete the parts of the autonomic nervous system (ANS) that deal with stress, specifically the sympathetic and the parasympathetic nervous system (Steeger et al., 2017). These two systems balance each other: When dealing with stressful events the body is turned on (i.e., fight or flight response) through an increased activity of the sympathetic nervous system. After the stressful situation is over (i.e., rest and digest response) our body is shut down again by increased activity of the parasympathetic nervous system. When the this system is activated too often or is not shut down properly, this might lead to continuous activity of the stress response system (McEwen, 1998). Repeated exposure to stressful life events might thus dysregulate our stress systems, contributing to behavioral precursors of psychopathology, and specifically externalizing problems (Bubier et al., 2009;Obradović et al., 2011).

Neighborhood greenness might buffer against these detrimental effects of stress (Wells and Evans, 2003) by specifically promoting activity of the *parasympathetic* nervous system (vs. the sympathetic nervous system) in restoring the body to a calm state after stress reactivity (Van den Berg et al., 2015). The role of the parasympathetic nervous system is to maintain homeostasis, or rest and digest. When we react to stress, activity of the parasympathetic nervous system decreases. Activity of the parasympathetic nervous system is often measured by respiratory sinus arrhythmia (RSA), which captures fluctuations in heart rate driven by the respiratory (or breathing) cycle. During a breathing cycle our heart rate speeds up when breathing in and slows down when breathing out. During stress these fluctuations in hearth rate decrease and during recovery from stress they increase.

Among the various measures of our nervous system, RSA was found one of the most robust biological markers for the stress response system, particularly in the context of externalizing behavior (Zisner and Beauchaine, 2016). Although findings on the role of RSA in the development of behavior (and psychopathology) are complex and not always consistent (see Zisner and Beauchaine, 2016), previous studies indicate that over time RSA might be affected by environmental stressors (Bubier et al., 2009; Obradović et al., 2011); is an indicator of emotion regulation and vulnerability to stress (Calkins and Dedmon, 2000); and is related to externalizing behavior problems (Hinnant and El-Sheikh, 2009; Obradović et al., 2011). Moreover, faster increases of RSA, indicating a faster rest and digest response, during stress recovery were found during and after exposure to nature (Van den Berg et al., 2015).

This longitudinal study will therefore examine whether stressful life events and neighborhood greenness during adolescence (between ages 11 and 16 years) predict externalizing behavior in late adolescence (at age 22), and will examine whether this relation is mediated by physiological stress recovery. We expect that a) neighborhood greenness has a negative relation with adolescent externalizing behavior (illustrated as path a in Fig. 1), specifically in interaction with stressful life events (i.e., protective factor, path b in Fig. 1) and b) that the interaction effect between stressful life events and neighborhood greenness on externalizing behavior problems is mediated by recovery after stress (i.e., RSA activity) (path c in Fig. 1).

1. Methods

1.1. Sample and procedure

Data were collected in a general population study called TRAILS (TRacking Adolescents' Individual Lives Survey), a large prospective study of Dutch adolescents with bi- or triennial measurements (i.e., T) from age 11 to early adulthood (see for information on recruitment and the cohort: (Huisman et al., 2008). A subsample of 715 adolescents (T1, *M*age = 11.1 years, *SD* = .55, 49.1% boys) performed specific laboratory tasks at T3. For this subsample, adolescents with high scores on frustration and fearfulness, low scores on effortful control, higher parental psychopathology, and living in a single-parent family were slightly oversampled. Our study used demographic and questionnaire data from T1, T2, (*M*age = 13.6), T3 (*M*age =16.3), and T5 (*M*age = 22.3 years), as well as physiological data collected during T3 from the subsample described above. Attrition in the TRAILS study was relatively low. Between T1 and T5 the retention rates ranged between 80% and 96% (Oldehinkel et al., 2014).

During the laboratory session adolescents participated in a social stress task during which their biological reactivity to stress was assessed. Participants were asked to refrain from smoking and from using coffee, milk, and sugar containing foods 2 h before the session. Stress reactivity and recovery was assessed in response to the Groningen Social Stress Task (GSST) a standardized protocol inspired by the Trier Social Stress Task (Kirschbaum et al., 2008). First, participants were instructed, on the spot, to prepare a 6-min speech about themselves and their lives and deliver this speech, while sitting in front of a video camera (i.e., public speech task). They were told that their videotaped performance would be judged by a panel of peers after the experiment. The test assistant watched the performance critically, without showing empathy or encouragement. Subsequently, they were asked to perform a mental arithmetic task for 6 min. Participants were instructed to repeatedly subtract the number 17 from a larger sum, starting with 13,278. The test assistant provided the participant with negative feedback (e.g., "No, wrong again, begin at 13,278"). Finally, participants were debriefed about the experiment.

1.2. Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. Each assessment wave of TRAILS was approved by the national ethical committee (CCMO, www.ccmo.nl; Protocol number of the fifth wave: NL38237.042.11).

1.3. Measures

Externalizing problems. Externalizing behavior problem were assessed through parents, using the Child Behavior Checklist (CBCL at T1) and Adult Behavior Checklist (ABCL at T5) (Achenbach and Rescorla, 2003; Achenbach et al., 2004). Externalizing behaviors, which are observable to others, are commonly assessed with parent-reported questionnaires (e.g., Henderson et al., 2019; Pinquart, 2017; Zandstra et al., 2018). The Adult Behavior Checklist is specifically developed to assess psychopathology in the general population through the reports of someone who knows the person well (usually the parent). This instrument is widely used and well-validated instrument (Achenbach and Rescorla, 2003; DeLuca et al., 2019; Tenneij and Koot, 2007). An aggregate of the subscales aggressive behavior, delinquent behavior, and intrusive behavior was used as an indicator of overall externalizing behavior (N = 35 items). Although the ABCL contains slightly different items than the CBCL (i.e., more appropriate for young adults) the symptoms covered were identical. Items were scored on a three-point Likert scale (0 = *not true* to 2 = *very or often true*). High internal consistency of the scale in both instrumentes was found, reliability of the CBCL externalizing problems scale at T1 was a = .90 and of the ABCL externalizing problems scale at T5 was a = .91. Mean scores for externalizing behavior were between 0 and 1.15 (M = .25; SD = .20) at T1 and between 0 and 0.83 (M = .17; SD = .20) at T5. At T5 this data was available for 633 participants.

Neighborhood greenness. Greenness was assessed as the percentage of adolescents' neighborhood area (using the postal code of the participants at T1, T2, and T3) that could be characterized as public green space (i.e., open green space or parks, Centraal Bureau voor de Statistiek, 2012). We specifically used a measure of *public* green spaces because this was previously shown to have a larger impact on health and well-being than the overall neighborhood vegetation level (Fan et al., 2011). Only 6.2% (between T1 and T2) and 11.2% (between T2 and T3) of participants moved to a different postal code area between measurement waves. The average change of greenness was therefore almost zero (-.0003% and -.0007% respectively). Subsequently, we used an aggregate mean score of neighborhood greenness on T1, T2, and T3, ranging from 0 to 29% (M = 7.06; SD = 6.67). This score was available for 599 participants. Since the average neighborhood greenness in The Netherlands is 9.3%, the neighborhood greenness in the current study seems to range from very low to very high.

Stressful life events. Stressful events which occurred between T1 and T3 were captured at age 16 years using the event history calendar (EHC). For the present study we modified the calendar into an interview on several life domains that lasted about 45 min. Participants were asked about events that occurred between ages 11–16 using a month-by-month horizontal timeline. Test–retest reliability was reasonable to good: >90% in a sample of adolescents (Caspi et al., 1996). Events were included that have previously been found to be experienced as negative, stressful and to bring change to someone's life, specifically family events such as death of a family member, parental divorce, mental problems within the family, school events such as changing schools or being expelled and other events such as being victim of a crime (McMahon et al., 2003). A sum score for the events was constructed indicating the number of stressors an adolescent was exposed to, ranging from 0 to 21 (M = 6.66; SD = 3.78). This data was available for 679 participants.

Respiratory sinus arrhythmia (RSA). RSA was measured during the lab session at T3 and was operationalized as the heart rate variability in the high-frequency band (0.15–0.40 Hz). Calculation of RSA was performed by power spectral analysis in the CARSPAN software program (Mulder et al., 1998). RSA mainly results from centrally mediated cardiac vagal activity (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). Lower scores (i.e., less variability) indicate low influence of the parasympathetic nervous system on cardiac function and therefore low stress response.

Stress reactivity was operationalized as the standardized residual of RSA during speech (360 s) predicted by RSA during rest (25 min post-test (300 s)). During the stress task, the average RSA decreased slightly (M = -258.16 ms2, SD = 2872.48; untransformed data) indicating that on average the task indeed deactivated the parasympathetic nervous system indicating stress reactivity. Stress recovery was operationalized as the residual of RSA after the stress task (6 min after post-test (150 s)) predicted by RSA reactivity during speech (360 s). After the stress task, the average RSA increased slightly (M = 567.45 ms2, SD = 3144.64; untransformed data) indicating that on average participants showed recovery from stress. A similar procedure was followed which has used and described in detail by (Nederhof et al., 2015). RSA reactivity to laboratory stressors has been found a valid measure for the autonomic nervous system and a biological marker for adaptive functioning (for a meta-analysis see Graziano and Derefinko, 2013). RSA in rest, RSA reactivity and RSA recovery was available for 677, 658, and 651 participants respectively.

Covariates. In addition, the following variables were included as covariates: sex, age at T1, externalizing behavior at T1 (CBCL), urbanization, and SES. Urbanization of the neighborhood was assessed by the number of residential addresses per 3.14 square kilometers (i.e., by drawing a circle with a radius of 1 km from participants' postal codes) (Reijneveld et al., 2010). The urbanization score changed for 8.2% of participants and the average change was very small, namely −17.45 number of residential addresses per square kilometer. Subsequently, we used an aggregate mean score of urbanization on T1 and T2, which ranged from 2 to 5362 addresses per 3.14 square kilometers. This data was available for all participants. SES was assessed per family using an average of standardized scores on income, education, and occupational level of parents (using the International Standard Classification of Occupations: Ganzeboom and Treiman, 1996). This data was available for 711 participants.

1.4. Analyses

We tested whether greenness was a promotive (i.e., directly reducing) or protective factor (i.e., indirectly, via reducing the detrimental effects of stressful life events) in adolescent externalizing behavior development by assessing the direct main effects and interaction effects between stressful life events and neighborhood greenness (aim 1). Secondly, we assessed mediation by stress recovery (RSA) using an indirect effect of stressful life events-by-neighborhood greenness on externalizing problems *via* RSA recovery (aim 2).

For all variables (except for the categorical variable of gender), extreme outliers were winsorized to 3 times the interquartile range (above the third quartile or below the first quartile) and variables were standardized. A multiple regression analysis, or a path-analysis, in M*plus* 7 was used, in which all hypotheses were tested in a single analysis. For testing moderation, or specifically whether neighborhood greenness moderated the effect of stressful life events on externalizing behavior, a product term (interaction) of stressful life events and neighborhood greenness was included in the analysis. For testing mediation, or specifically whether stressful life events-by-neighborhood greenness predicted externalizing behavior *via RSA* recovery, an indirect effect was included in the analysis. Full information maximum likelihood (FIML) was used to treat missing data (i.e., a likelihood function for each participant was estimated based on the variables that are present so that all the available data are used) (Wothke, 2000). To ensure the robustness of results, bootstrapped 95% confidence intervals (CI) were used to assess the effects. Our model has a 16.25 to 1; cases to free parameter ratio. The sample size should be large enough to detect small effects (f^2 = .04) with a power of .80 and α = .05 (Faul et al., 2007). Model fit was assessed using the Root Mean Square Error of Approximation (RMSEA) (model fit satisfactory when < 0.08) and Tucker-Lewis Index (TLI) (model fit satisfactory when > 0.90).

2. Results

2.1. Correlations between variables

Urbanization was positively related to age and SES. Stressful life events were positively, and SES negatively, associated with externalizing behavior at T1 and T5. Higher RSA in rest was associated with higher externalizing behavior at T1 and T5. Boys showed higher RSA reactivity to stress and higher RSA recovery than girls. Moreover, externalizing behavior at T1 was strongly and positively related with externalizing behavior at T5 (see Table 1 for descriptive statistics and correlations).

Table 1
Descriptive statistics and bivariate correlations of all variables.

		M	SD	2	3	4	5	6	7	8	9	10	11
1.	Age at T1	11.10	0.55	.01	-.01	.17**	.07	.07	-.04	-.01	.04	-.00	.04
2.	Sex (% boys) [a]	49.10		–	-.01	-.05	-.01	-.02	.04	.12**	-.14**	.21**	.06
3.	SES T1 (% low SES) [b]	20.10		–	–	.08*	-.29**	.02	-.05	.02	.02	-.22**	-.18**
4	Urbanization T1-T2 [c]	1488	1047	–	–	–	.07	.06	-.06	-.00	.02	.06	.01
5	Stressful life events T1-T3	6.66	3.78	–	–	–	–	.04	.03	-.03	.03	.26**	.32**
6.	Neighborhood greenness T1-T3[d]	7.06	6.67	–	–	–	–	–	.06	-.04	.03	-.02	.01
7.	RSA rest T3	1778.20	1827.18	–	–	–	–	–	–	-.55**	.33**	.09*	.12*
8.	RSA reactivity T3[e]	−119.565	1518.52	–	–	–	–	–	–	–	-.63**	-.00	-.02
9	RSA recovery T3 [c]	483.01	1907.00	–	–	–	–	–	–	–	–	-.05	.02
10	Externalizing behavior T1	0.25	0.20	–	–	–	–	–	–	–	–	–	.47**
11	Externalizing behavior T5	0.17	0.20	–	–	–	–	–	–	–	–	–	–

Note. a: 0 = female; 1 = male; b: average of standardized scores on income level, educational level, and occupational level of both parents, in analyses this is a continuous score; c: the number of residential addresses per 3.14 square kilometers; d: percentage of urban green space, parks and forest land use in neighborhood (national average is 9.3%, see https://opendata.cbs.nl/statline/portal.html); e:.Change scores; *p < .05; **p < .01.

Table 2
Results of Multi-variate Regression Analysis, Including Covariates, Main effects, Interaction-effects, and Mediation.

		Predictor	Outcome	*B*	*SE*	*Beta*[a]	*95% CI of B*	*p*
Covariates		Externalizing problems T1	Externalizing problems T5	.42	.04	.42	.34 - .50	<.001
		Age	Externalizing problems T5	.03	.04	.03	-.05 - .09	.48
		Sex[b]	Externalizing problems T5	-.01	.07	-.01	-.14 - .12	.85
		SES	Externalizing problems T5	.00	.98	.00	-.02 - .00	.98
Neighborhood		Urbanization	Externalizing problems T5	-.03	.03	-.03	-.09 - .04	.31
main effects	aim 1: Promotive	Neighborhood greenness	Externalizing problems T5	.01	.04	.01	-.06 - .09	.80
Interaction		RSA recovery	Externalizing problems T5	.05	.04	.05	-.03 - .13	.26
		Stressful life events	Externalizing problems T5	.22	.04	.22	.14 - .30	<.001
	aim 1: Protective	Stressful life events × neighborhood greenness	Externalizing problems T5	.09	.04	.09	.01 - .17	.03
Indirect		Stressful life events	RSA recovery	.05	.05	.05	-.04 - .14	.28
		Neighborhood greenness	RSA recovery	.03	.04	.03	-.05 - .12	.48
		Stressful life events × neighborhood greenness	RSA recovery	.08	.06	.08	-.04 - .19	.19
	aim 2: Mechanism	Stressful life events × neighborhood greenness *via* RSA	Externalizing problems T5	.00	.01	.00	-.00 - .02	.46

Note. $\chi 2(N = 715, 5) = 9.283$ CFI = .978, RMSEA = .035; a: Corrected Beta's for other variables in model; SE = standard error; b: 0 = female; 1 = male.

2.2. Multivariate regression

All control variables, direct, interaction, and indirect effects were included in a multi-variate analysis, which showed good model fit: $\chi^2(N = 715, 5) = 9.283$ CFI = .978, RMSEA = .035 (see Table 2). We further present results per aim:

Aim 1: promotive or protective effect of neighborhood greenness.

Promotive effect. The results show that, controlling for age, sex, SES, urbanization, and externalizing behavior at T1, stressful life events predict externalizing behavior at T5 ($B = .22$, $SE = .04$, $p < .001$; 95% CI: .14 - .30, see main effects line of Table 2). That is, adolescents who experienced more stressful events reported more externalizing problems five years later. Neighborhood greenness did not directly predict externalizing behavior. This means neighborhood greenness is not a promotive factor in the development of adolescent externalizing behavior.

Protective effect. Our results show an interaction between stressful life events and neighborhood greenness ($B = .09$, $SE = .04$, $p = .03$; 95% CI: .01 - .17) (see interaction line of Table 2). Post hoc analyses using the Johnson-Neyman regions of significance (Clavel, 2015) show that stressful life events predict externalizing behavior in the entire range of greenness (i.e., more stressful life events were related to more subsequent externalizing behavior, independent of neighborhood greenness). However, the strength of this relationship increases as neighborhood greenness increases (i.e., more neighborhood greenness predicts a stronger effect of stressful life events on externalizing behavior) (see Fig. 2): For adolescents living in greener neighborhoods (1 *SD* above the mean) the effects of stressful life events on externalizing behavior are stronger ($B = .31$, $SE = .07$, $p < .001$; 95% CI: .17 - .45) than for adolescents living in less green neighborhoods (1 *SD* below the mean: $B = .13$, $SE = .06$, $p = .03$; 95% CI: .01 - .26).

Aim 2: underlying mechanism

Mediation by RSA. There was no indirect effect from stressful life events-by-neighborhood greenness on externalizing behavior *via* RSA at recovery ($B = .00$, $SE = .01$, $p = .64$; 95% CI: -.00 - .02) (see mediation line of Table 2). The effects of stress and neighborhood greenness were therefore not mediated by stress recovery.

Because some of our covariates were correlated, as a robustness check, we repeated our analysis without covariates. Overall, findings remained the same (see Table A1, Supplement A).

3. Discussion

In a longitudinal multi-method study we tested whether neighborhood greenness is a promotive (i.e., has a direct reducing effect) or protective (i.e., interacts with stressful life events) factor in the development of externalizing behavior problems (maladaptive behaviors directed toward an individual's environment), such as aggressive and rule-breaking, behavior, in adolescence. Our results showed that only stressful life events (not SES, urbanization, neighborhood greenness or the parasympathetic nervous system measures with respiratory sinus arrhythmia (RSA)) predicted externalizing behavior in late adolescence, both alone and in interaction with neighborhood greenness. Controlling for SES and urbanization, our study did not confirm previous findings that neighborhood greenness is directly related to externalizing behavior (Flouri et al., 2014; Markevych et al., 2014; Younan et al., 2016).

Most previous research on the effects of nature on mental health and behavior has, however, been conducted on either adults or children (for a review see Gascon et al., 2015). Our results might therefore simply show that neighborhood greenness is not directly related to externalizing behavior problems in late adolescence. Neighborhood greenness may not have the same effects on behavior across the life span. Indeed, a recent study on Dutch adults found age differences in the effect of neighborhood greenness on mental health (Bos et al., 2016). Specifically, and in contrast with other age-groups, they found negative effects of neighborhood greenness in the age group 45 and 54 years. Bos and colleagues suggest that these differences might be explained by differences in the usage of green spots. Neighborhood green spots might be used by children as play areas and by adults (of most ages) for exercise and recreation, such as walks, but adolescents may not use or may differently use these area's. Different areas of the neighborhood might be used for recreation in this age group.

Our study does not inform us on the *use* of neighborhood green space or engagement. This may be important, since among college students the effects of spending time in green spaces on their quality of life, mood, and stress were stronger when students were actively engaged (Holt et al., 2019). Different types of nature exposure may affect adolescent behavior through different mechanisms. For example, active exposure to green space may (partly) affect behavior through the positive effects of physical activity, whereas passive exposure to green space may affect behavior through stress restoration or protection against urban noise and pollution (e.g., Donnelly et al., 2016; Klingberg et al., 2017; Markevych et al., 2017).

Our findings do suggest that neighborhood greenness is indirectly related to externalizing problem behaviors of adolescents, in such that together with stressful life events it is a risk factor for externalizing behavior problems. The effect of stressful life events on externalizing behavior was stronger for adolescents who grew up in *greener* neighborhoods than for adolescents who grew up in less green neighborhoods. This might indicate that in adolescence neighborhood greenness is a correlate of other factors that influence (the effect of stressful life

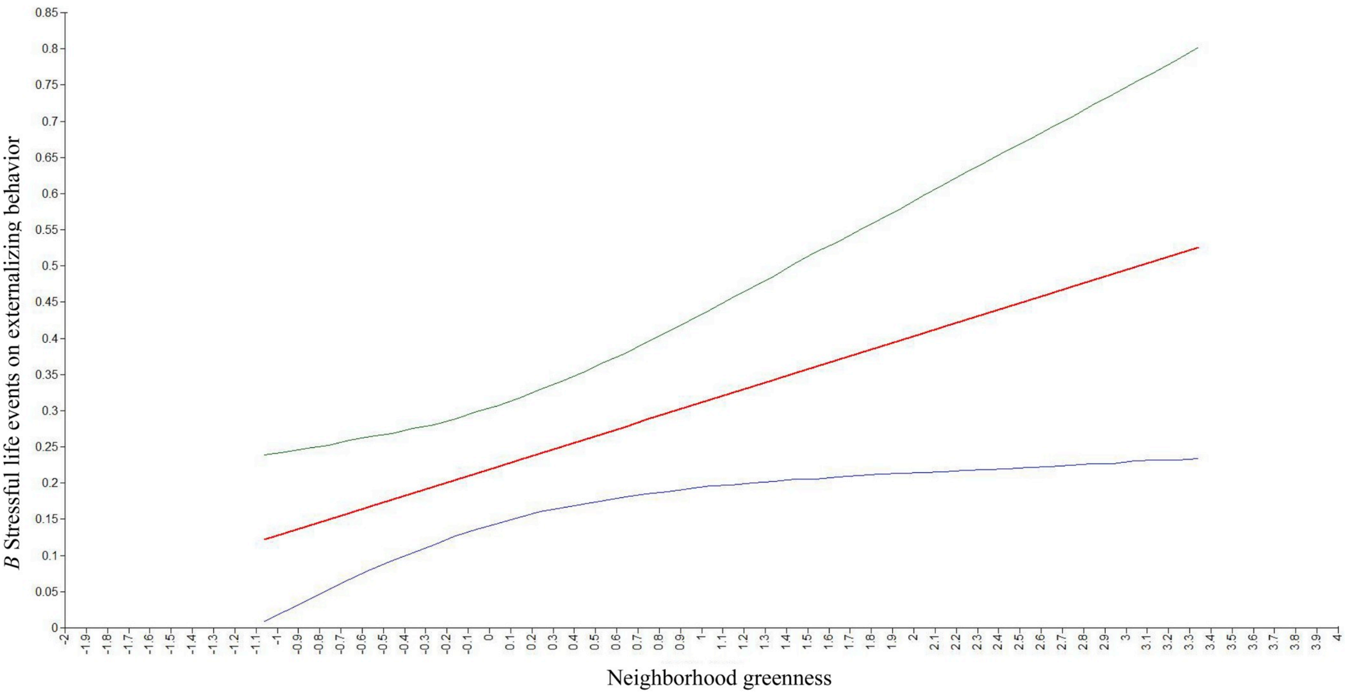

Fig. 2. Illustration of the Effect of Stressful Life Events on Externalizing Behavior Moderated by Neighborhood Greenness.
Note. The X-axis depicts a continuous range of neighborhood greenness (standardized). The Y – axis depicts a continuous range of values for the adjusted effect of stressful life events on externalizing behavior. The middle (red) plot line represents values of the adjusted effect that correspond to the full range of all continuous values of neighborhood greenness. The curved lines above and below this plot line represent 95% confidence bands around the adjusted effect. The effect of stressful life events is significant across the full range of neighborhood greenness. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

events on) externalizing behavior. For example, neighborhood greenness might be indirectly related to externalizing behavior via its effect on social control, community cohesion, parenting and peer affiliations (as was found for other neighborhood characteristics: e.g., Cantillon, 2006). Some of these confounders of neighborhood greenness may also foster externalizing behaviors.

Specifically, neighborhood greenness might be positively correlated with the presence of shielded areas, away from the eyes of adults, and thus with the opportunity for unsupervised time spent out in the community without surveillance or fear of being caught. This has in turn been related to externalizing behavior (Beyers et al., 2003). Indeed, it was found, for example, that adolescents living in areas with more parks more often engage in substance use compared to those living in areas with fewer parks (Kotlaja et al., 2018). Moreover, adolescents might cope with stress by seeking social contacts with their peers and being outdoors, including hanging out in local green space (see Roe et al., 2017). Adolescents who experience stressful life events might spend more time outside the family environment, with (deviant) peers, engaging in externalizing behaviors, specifically when the neighborhood provides them with opportunities to do so.

Besides testing mere relations between variables over time we also explored stress recovery as biological mechanisms underlying the effects of neighborhood greenness on externalizing problems over time. Our results show that – although on average participants showed RSA reactivity to the lab stress task, as well as recovery afterwards (i.e., successful manipulation) – individual differences in RSA recovery were not related to externalizing behavior and did not mediate the effects of stress and neighborhood characteristics. We thus found no evidence that neighborhood greenness buffers against the negative effects of stress via the stress response system (i.e., stress recovery hypothesis).

Our findings have to be interpreted in light of some limitations. First of all, our study design does not allow us to conclude on causal relations between stressful life events, neighborhood greenness and externalizing behavior problems. There could be a third, unmeasured, factor explaining the relations between these constructs. Second, we used a community sample and thus the average score on externalizing behavior was low, specifically at the last time-point. This means our findings may not generalize to at risk populations or to adolescents with clinical behavioral problems. Third, one informant, namely the parent, was used to assess externalizing behavior. Although parent-reports have been shown to be a valid measure of externalizing behavior, these reports are limited to the context in which parents observe this behavior. Different informants may provide information on different and unique aspect of adolescent functioning and may lead to different findings. Finally, collecting data on stressful life events in retrospect may lead to an under-, or overestimation of these events.

Our study overcomes important limitations of most previous work on neighborhood greenness in adolescents, by using different informants and time-points for reducing codependency between variables; taking into account a timeline for mediation; and adding an interaction effect to distinguish between promotive and protective factors. Using a stringent test of moderation and mediation we found no evidence that neighborhood greenness positively affects adolescent externalizing behavior development, either directly or via individual differences in RSA recovery. Overall, this study shows that in regard to adolescents' neighborhood it might not necessarily be "the greener the better". Our findings might be important since they question a universal positive effect of a green neighborhood.

From an empirical point of view, our results might indicate that neighborhood greenness affects health in different ways across different developmental periods. For example, there might be critical (i.e., restricted developmental periods in which greenness is important) or sensitive periods (i.e., developmental periods in which the effects are more likely to occur) for the effects of neighborhood greenness on mental health. This would emphasize the importance of assessing risk, promotive, and protective factors, and underlying their mechanisms, over different developmental periods. Our results also raise the question which specific aspects of neighborhood greenness are beneficial for our mental health, in which developmental periods, and why these specific aspects are beneficial.

Theoretically driven hypotheses on working mechanisms may inform us on which populations, type of neighborhood greenness (e.g., vegetation, access to parks or forests, window view), and outcome measure are most informative or appropriate. This is important, since different measures for neighborhood greenness and the outcome behavior might lead to different results (Gascon et al., 2015; Feng and Astell-Burt, 2017; Reid et al., 2018). For example, if we hypothesize that neighborhood greenness affects feelings of stress through its restorative qualities it may be most informative to measure greenness through subjective aesthetic quality and the outcome via subjective wellbeing. However, if we hypothesize neighborhood greenness to work via social and physical processes (e.g., hanging out with friends, physical exercise) then location and activity tracking, or experience sampling methods, may be more informative.

From a clinical or public health point of view, our results may suggest that neighborhood greenness has little effect on adolescent behavior and/or that factors within adolescents' homes are more important in predicting (mal)adjustment than factors around adolescent's homes. Alternatively, they may be interpreted as that when adolescent are dealing with stressful life events, certain neighborhood characteristics might indirectly have a negative influence on their behavior, for example via the lack of social control, or via affiliation with delinquent peers. Neighborhood greenness might in some cases thus be a marker for other neighborhood characteristics promoting problem behavior. However, before previous or current findings on neighborhood greenness can have any true clinical or societal meaning we first need to know *how* neighborhood greenness affects adolescent behavior and mental health.

Conflicts of interest

The authors declare that they have no conflict of interest.

Acknowledgments

This research is part of the TRacking Adolescents' Individual Lives Survey (TRAILS). Participating centers of TRAILS include various departments of the University Medical Center and University of Groningen, the Erasmus University Medical Center Rotterdam, the University of Utrecht, the Radboud Medical Center Nijmegen, and the Parnassia Bavo group, all in the Netherlands. TRAILS has been financially supported by various grants from the Netherlands Organization for Scientific Research NWO (Medical Research Council program grant GB-MW 940-38-011; ZonMW Brainpower grant 100-001-004; ZonMw Risk Behavior and Dependence grants 60-60600-98-018 and 60-60600-97-118; ZonMw Culture and Health grant 261-98-710; Social Sciences Council medium-sized investment grants GB-MaGW 480-01-006 and GB-MaGW 480-07-001; Social Sciences Council project grants GB-MaGW 457-03-018, GB-MaGW 452-04-314, and GB-MaGW 452-06-004; NWO large-sized investment grant 175.010.2003.005); the Sophia Foundation for Medical Research (projects 301 and 393), the Dutch Ministry of Justice (WODC), the European Science Foundation (EuroSTRESS project FP-006), and the participating universities. We are grateful to all adolescents, their parents and teachers who participated in this research and to everyone who worked on this project and made it possible.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2019.102163.

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