Environmental Research 208 (2022) 112603

Contents lists available at ScienceDirect

Environmental Research

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

Residential green space is associated with a buffering effect on stress responses during the COVID-19 pandemic in mothers of young children, a prospective study.

Stijn Vos [a], Esmée M. Bijnens [a,b], Eleni Renaers [a], Hanne Croons [a], Charlotte Van Der Stukken [a], Dries S. Martens [a], Michelle Plusquin [a], Tim S. Nawrot [a,c,*]

[a] Centre for Environmental Sciences, Hasselt University, Agoralaan Building D, 3590, Diepenbeek, Belgium
[b] Department of Human Structure and Repair, Ghent University Hospital, Corneel Heymanslaan 10, 9000, Ghent, Belgium
[c] Department of Public Health, Leuven University (KU Leuven), Kapucijnenvoer 35, 3000, Leuven, Belgium

ARTICLE INFO

Keywords:
COVID-19
Well-being
Stress
Green space
Nature
Epidemiology

ABSTRACT

Green spaces are associated with increased well-being and reduced risk of developing psychiatric disorders. In this study, we aimed to investigate how residential proximity to green spaces was associated with stress response buffering during the COVID-19 pandemic in a prospective cohort of young mothers. We collected information on stress in 766 mothers (mean age: 36.6 years) from the ENVIR*ON*AGE birth cohort at baseline of the study (from 2010 onwards), and during the COVID-19 pandemic (from December 2020 until May 2021). Self-reported stress responses due to the COVID-19 pandemic were the outcome measure. Green space was quantified in several radiuses around the residence based on high-resolution (1 m^2) data. Using ordinal logistic regression, we estimated the odds of better resistance to reported stress, while controlling for age, socio-economic status, stress related to care for children, urbanicity, and household change in income during the pandemic. In sensitivity analyses we corrected for pre-pandemic stress levels, BMI, physical activity, and changes in health-related habits during the pandemic. We found that for an inter-quartile range contrast in residential green space 300 m and 500 m around the residence, participants were respectively 24% (OR = 1.24, 95%CI: 1.03 to 1.51) and 29% (OR = 1.29, 95%CI: 1.04 to 1.60) more likely to be in a more resistant category, independent of the aforementioned factors. These results remained robust after additionally controlling for pre-pandemic stress levels, BMI, physical activity, smoking status, urbanicity, psychological disorders, and changes in health-related habits during the pandemic. This prospective study in young mothers highlights the importance of proximity to green spaces, especially during challenging times.

1. Introduction

In early 2020, the onset of the COVID-19 pandemic upset the balance of regular life. Not only did the disease itself cost many lives, but in an effort to limit the spread of the virus and to safeguard the capacity of health services, governments worldwide were forced to adopt far-reaching safety measures. Over the course of the year, lockdowns, quarantines, self-isolating practices and social distancing became the norm in many countries around the world. Additionally, people had fewer options in terms of spending their free time, as recreational activities that involved close contact with other people were either not allowed or were heavily restricted. Meanwhile, many potential sources of psychological stress remained or were actively worsened, for example by a lack of financial stability, as was the case for many people working in catering industries. The pandemic posed specific challenges for parents, considering the changed conditions for education and day-care activities, which required parents to adapt and balance family and work activities according to the new circumstances, adding to stress levels Additionally, specific pandemic related anxieties such as the fear for the spread of the virus, or the fear for causing harm to oneself or to loved ones were common. In short, during the COVID-19 pandemic, regular life stressors went on, or were aggravated with pandemic-specific anxieties and fears. Meanwhile, the possibilities to cope with said stressors were more limited than before the onset of the pandemic, thereby challenging people's psychological well-being. Evidence from previous epidemics suggests that confinement negatively impacts individual's wellbeing due to reduced intellectual and social stimulation, reduced resources and material support (Brooks et al., 2020). On the

* Corresponding author. Agoralaan building D, 3590, Diepenbeek, Belgium.
E-mail address: tim.nawrot@uhasselt.be (T.S. Nawrot).

https://doi.org/10.1016/j.envres.2021.112603
Received 15 October 2021; Received in revised form 10 December 2021; Accepted 18 December 2021
Available online 4 January 2022
0013-9351/

other hand, it should be noted that the pandemic conditions may have had positive effects for young parents that were able to adapt well to the new situations, as some stressors may be reduced due to the ability to work from home.

Since regular life and recreational activities were disrupted, many people have sought out alternative ways to spend their free time and cope with life stressors. Spending time in natural areas quickly became more popular (Christina)Innes et al. (2021); Volenec et al. (2021), since it was possible to engage with activities in green spaces without high risk for spreading the disease. In recent years, several researchers have demonstrated positive associations between residential green space have and many different health outcomes, including – but not limited to – heart rate (Kondo et al., 2018), blood pressure (Jimenez et al., 2020), cardiovascular mortality (Gascon et al., 2016), and all-cause mortality (Ji et al., 2020; Rojas-Rueda et al., 2019). Residential proximity to green spaces is associated with reduced stress and the healthy regulation of cortisol levels (Roe et al., 2013). Furthermore, exposure to green spaces has been associated with decreased anxiety and depression related intrusive thoughts (Beyer et al., 2014; Gascon et al., 2015, 2018; Bratman et al., 2019; Henson et al., 2020)–(Beyer et al., 2014; Gascon et al., 2015, 2018; Bratman et al., 2019; Henson et al., 2020), and is associated with reduced risk for psychiatric disorders such as major depressive disorder (Engemann et al., 2019; Sarkar et al., 2018). Additionally, green spaces facilitate social cohesion and interactions (Weinstein et al., 2015; van den Berg et al., 2019), which likely served as an especially important protective mechanism during the COVID-19 pandemic, during which social interactions were otherwise severely limited.

To summarize, the pandemic posed specific challenges to parents of young children, which puts young parents at risk for worse mental health states during the pandemic (such as increased stress levels or fear and/or worries for the future). This may lead to worse health outcomes for the whole family, since poor mental health in caregivers is associated with worse health outcomes among their children (Leijdesdorff et al., 2017; Pierce et al., 2020; Wolicki et al., 2021). We hypothesize that residential proximity to green spaces during the pandemic may serve as a protective factor for young families. Therefore, in this study we aimed to investigate how residential proximity to green spaces relates to COVID-19 pandemic stress responses in a prospective cohort of newborn-mother pairs. We additionally investigated whether residential proximity to green spaces was related to changes in physical activity habits during the pandemic.

2. Methods

2.1. Study design

The ENVIRonmental influences *ON* early AGEing (ENVIR*ON*AGE) birth cohort was established in 2011 and recruits pairs of mothers and neonates (singleton births only) at birth at the East-Limburg Hospital (Genk, Belgium). The catchment area of the cohort is located in the north-east of Belgium, in the province of Limburg, Flanders. The Ethics Committee of Hasselt University and the East-Limburg Hospital approved the study protocol that was carried out following the Declaration of Helsinki. Written informed consent was obtained from all participating mothers. The inclusion criteria were mothers who provided informed consent and were able to fill out the questionnaires in Dutch. Full details of the study design have been published previously (Janssen et al., 2017). All participants completed at recruitment of the study detailed information on maternal age, body mass index (BMI) prior to pregnancy, maternal education, occupation, self-reported smoking status and history, physical activity (being physically active for more than 20 min less than once a week, once a week, twice or more per week), place of residence, history of psychiatric disorders, parity, and ethnicity. Maternal education was coded as "low" (no diploma or primary school), "middle" (high school), or "high" (college or university degree). Residential addresses and education status have been updated for those participating in clinical measures four years after the date of recruitment. Data on baseline stress levels (Perceived Stress Scale (Cohen et al., 1983) scores) were available for a subset of participants (n = 613, PSS scale was included since the first revised version of the recruitment questionnaire, introduced in 2012).

From December 23rd, 2020 until May 1st, 2021, 1680 participants from the ENVIRONAGE birth cohort (located in Belgium) were contacted and were asked to fill out an online survey. Participants that did not respond to the online survey were sent a letter with a paper version of the same questionnaire. In total, 766 participants responded to the request to fill in the questionnaire (response rate = 45.6%). Background characteristics of the participants differed to non-participants with respect to mean age (36.6 vs 35.4 years old respectively, $p < 0.01$) and education level (low, medium, and high: 5.0%, 29.3%, and 65.7% vs 13.7%, 41.2%, and 45.1% respectively, $p < 0.01$).

The study was conducted at the tail end of a second large wave of COVID-19 infections in Belgium, which roughly lasted from October until the end of December 2020. At the time of the study, the following COVID-19 safety measures were in effect in the study area: an evening curfew for all citizens from midnight until 5:00 a.m., restrictions on the number of people you could meet at a time to 4 people (while following social distancing rules and wearing a face mask), a maximum of one close contact person (meaning, one contact person you could meet without following social distancing rules and wearing a face mask), trips abroad were strongly discouraged, and working from home was strongly recommended when possible. Non-essential stores were open under strict conditions (hand sanitizers at entrance, mandatory face masks, maximum of 30 min in the store, maximum of one person per 10 m2). Non-medical close contact professions (hair dressers, beauty salons, …) were not allowed to operate. Vacation parks, camping grounds and zoos were closed. Swimming pools and museums were open under specific conditions (maximum capacity, social distancing, face masks in museums). None of these safety measures were relaxed for the end of the year holidays.

The questionnaire contained questions regarding the participants well-being during the COVID-19 pandemic. We also obtained updated information on diagnosed psychiatric disorders (depression, anxiety disorders and burn-out). The participants were asked about their personal experiences with the virus, their general mental health, changes in habits (healthy diet, smoking behaviour, alcohol consumption, physical activity) due to the pandemic, and changes in household monthly income. For this study, the outcome of interest was "COVID-19 related stress and fear", an outcome measure we constructed from the answers to the following questions:

> "On a scale from 1 (strongly disagree) through 5 (strongly agree), to what extent do you agree with the following statements:

- *In general, I feel more stressed than before the COVID-19 pandemic.*
- *In general, I feel more worried about the future than before the COVID-19 pandemic."*

Based on the response (score ranging between 1 and 5) to both question, participants were divided into four categories which reflect the degree to which participants agreed with one or both statements. Participants with sum scores less than 4 either disagreed with both statements, or were neutral about one and disagreed strongly with the other. These mothers were categorized as most resistant to increased stress. Participants with sum scores of 5 or 6 were neutral on both statements, or agreed moderately with one and disagreed with the other. Therefore, those individuals were classified as high-to-medium resistant. Mothers with sum scores of 7 or 8 agreed moderately with both statements, or strongly with one statement and were at least neutral on the other statement, and were therefore considered medium-to-low

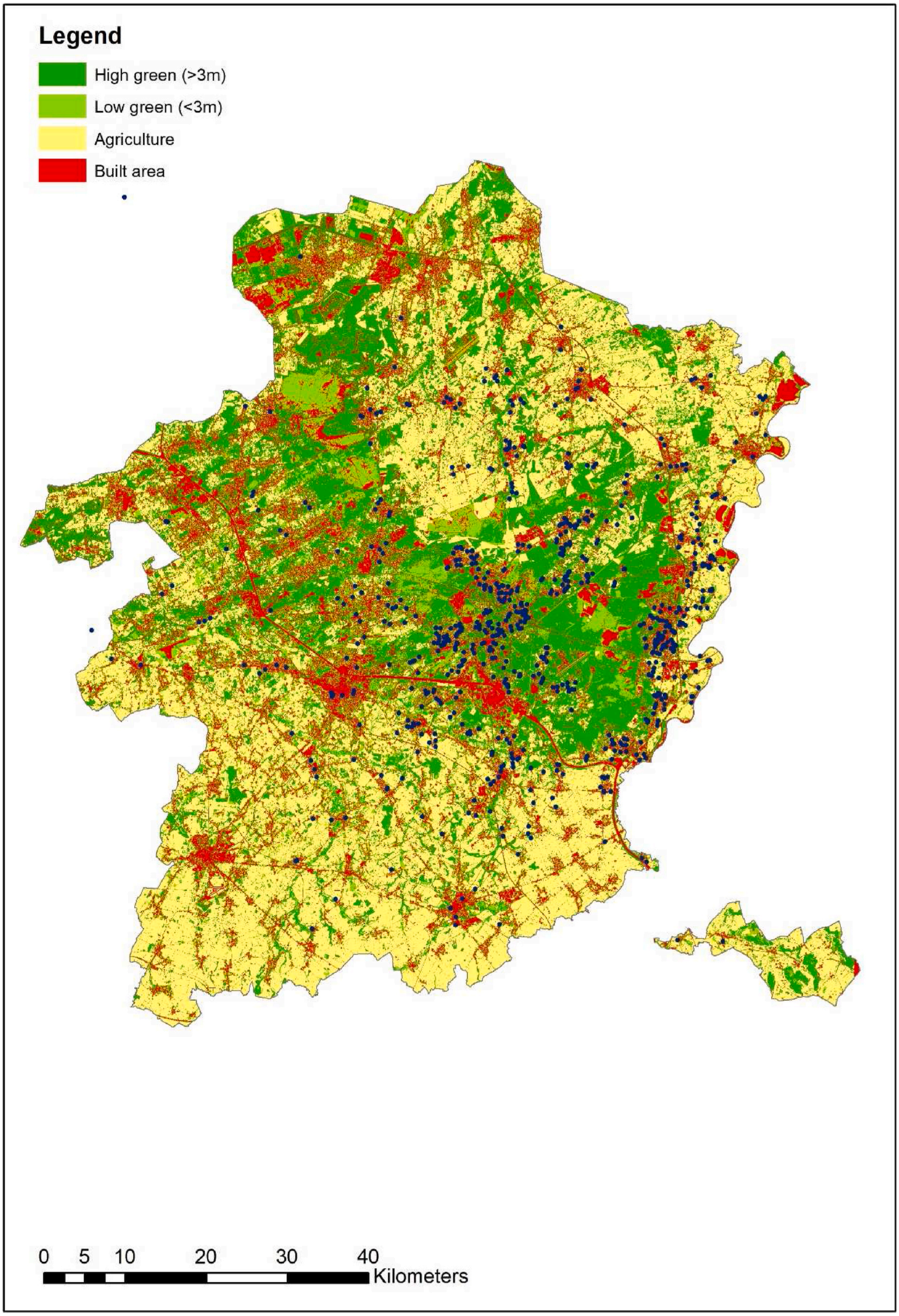


Fig. 1. Graphical representation of the study area and population. The blue dots represent the residential location of the study participants. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

resistant. Finally, participants belonging to the least resistant category agreed at strongly with one statement and moderately with the other, or strongly agreed with both statements (sum scores of 9 or 10, least resistant category).

2.2. Green space assessment and urbanicity

Green space assessment was performed using Geographic Information System (GIS) functions with the ArcGIS 10 software package (Esri, California, United States of America). The participant's residential addresses were geocoded (Fig. 1). The residential locations were categorized as urban, suburban or rural based on map data by the Flemish Government (department Environment) containing all statistical sectors in Flanders classified as urban, suburban or rural areas depending on population density, employment types, location and spatial planning characteristics. Green space was estimated in several radius distances (50 m, 100 m, 300 m, 500 m, and 1000 m) around the residence based on a high-resolution (1 m^2) land cover map; the Green Map of Flanders 2012 from the Agency for Geographic Information Flanders (AGIV). This land cover map was constructed based on orthographic images collected by flights during the summer of 2012 and contains information about vegetation with height lower than 3 m ("low green"), vegetation with height higher than 3 m ("high green") and the total vegetation cover ("total green"), which is the sum total of the other two vegetation covers.

2.3. Statistical analysis

All statistical analyses were performed using R version 4.0.2 (R Core Team, Vienna, Austria). The threshold for statistical significance was set at a 95% confidence level ($p < 0.05$). The correlation between the two indicator questions was determined by calculating the Spearman Rank correlation coefficient. Because the outcome categories are ordered (meaning that, in this case, a lower category is less favourable than a higher category), we used an ordinal logistic regression model to estimate the Odds Ratios (OR) of participants belonging to a more favourable category of resistance to increased stress and/or fear during the pandemic. Additionally, ordinal logistic regression models were used to estimate the Odds Ratios (OR) for reporting more physical activity (long walks, cycling, jogging, …) during the pandemic as compared to before. The presented effect estimates represent the difference in Odds Ratios (with 95% CI) for an interquartile range (IQR) increase in percentage green space in several buffers around the residential address. Covariates were selected *a priori* (for a DAG showing the hypothesised relations between these selected covariates, the exposure and the outcome, see Supplemental Figure 1). All models were adjusted for change in income during the pandemic, the participants socio-economic status (as indicated by highest attained degree), age and urbanicity. Additionally, we adjusted for self-reported stress related to the care for their children during the pandemic. As sensitivity analyses, we additionally adjusted for baseline stress (PSS scores at the time of recruitment), previously diagnosed mental health conditions (self-reported history of diagnosed depressive disorders, anxiety disorders or burn-out), number of self-reported pack-years at the time of recruitment (i.e. packs per day multiplied by the number of years they reported smoking), pre-pandemic physical activity (indicated by self-reported weekly frequency of physical exercise at the time of recruitment), pre-pregnancy BMI, and reported changes in habits due to the pandemic (with regards to dietary habits, alcohol consumption, smoking behaviour and physical activity).

3. Results

3.1. Characteristics of the study population

The descriptive characteristics of the study population are summarized in Table 1. The study consisted of 766 mothers with a mean age of

Table 1
Descriptive characteristics of the study population. n = 766[a].

	Mean (range, SD)	Number (%)
Age (years)	37 (24–52, 4.9)	
Education level		
Low		38 (5.0%)
Medium		225 (29.3%)
High		503 (65.7%)
Change in income (during the pandemic)		
Loss of income		145 (18.9%)
Increase in income		20 (2.6%)
No change in income		601 (78.5%)
Stress related to care for children (during the pandemic)		
None		289 (37.7%)
Low		269 (35.1%)
Medium		156 (20.4%)
High		52 (6.8%)
Urbanicity		
Rural		386 (50.4%)
Suburban		167 (21.8%)
Urban		213 (27.8%)
Previously diagnosed psychological disorders		
Depression		94 (12.3%)
Anxiety disorder		38 (5.0%)
Burn-out		25 (3.3%)
Smoking (time of recruitment)		
Never-smokers		557 (72.7%)
Smoked before pregnancy		147 (19.2%)
Smoked during pregnancy		62 (8.09%)
Number of pack-years (smokers only)	5.8 (0.1–34, 5.9)	
Physical activity (time of recruitment)		
Less than once per week		206 (27.7%)
Once per week		160 (21.5%)
Twice or more per week		377 (50.7%)
Baseline stress levels (time of recruitment)		
Perceived Stress Scale score[a]	13.1 (0–55, 6.9)	
Smoking habits (during the pandemic)		
Does not smoke		694 (90.6%)
Less frequent smoking		11 (1.4%)
No change in frequency of smoking		33 (4.3%)
More frequent smoking		28 (3.7%)
Alcohol consumption (during the pandemic)		
Does not drink alcoholic beverages		327 (42.7%)
Less consumption		96 (12.5%)
No change in consumption		210 (27.4%)
More consumption		133 (17.4%)
Dietary habits during pandemic (during the pandemic)		
Less healthy diet		182 (23.8%)
No change in diet		468 (61.1%)

(*continued on next page*)

Table 1 (*continued*)

	Mean (range, SD)	Number (%)
Healthier diet		103 (13.4%)
Physical activity (long walks, cycling, jogging, during the pandemic)		
Less frequent physical activity		192 (25.1%)
No change in physical activity		294 (38.4%)
More frequent physical activity		280 (36.6%)

[a] PSS scores at the time of recruitment were available for 613 of the 766 participants.

36.6 years (range: 24 to 52). Most women never smoked at the baseline of the study (72.7%), and had obtained a higher education degree (college or university, 65.7%). Most participants (78.5%) reported no change in monthly household income during the COVID-19 pandemic compared to their situation before the pandemic, 18.9% of the participants reported a comparatively lower monthly household income, and a small number of participants (2.6%) reported an increase in their monthly income. Most women did not report increased stress related to the care for their children (37.7%), whereas a relatively large number of participants did report slightly, moderately or much higher stress levels due to parental responsibilities during the pandemic (35.1%, 20.4%, and 6.8% respectively). 94 participants (12.3%) reported previous diagnoses of one mental disorder (depression, anxiety disorders or burn-out), and 22 participants (2.9%) reported more than one of these disorders. The average time between the date of recruitment and the final date of the COVID-19 questionnaire responses was 6.0 years (range: 0.5–11.2 years, SD: 2.8 years). The mean Perceived Stress Scale score for all participants at the time of recruitment was 13.2 (range: 0 to 55, SD: 5.9). The distribution of residential green space percentages in the different sized buffers around the residence is summarized in Table 2.

3.2. COVID-19 related stress and fears

Fig. 2 shows the distribution of the sum scores on the two indicator questions for all participants. Answers on the separate stress and the fear indicator questions were significantly correlated ($r = 0.40$, $p < 0.01$). Most mothers (355, 46.3%) fell into the medium-to-low resistant category (sum score = 7 or 8). The second most frequent category (184, 24.0%) was the medium-to-high resistant category (sum score = 5 or 6). 170 participants (22.2%) belonged to the lowest resistant category (sum score = 9 or 10), whereas 57 mothers (7.4%) were in the most resistant category (sum score <4).

3.3. Residential green, COVID-19 related stress, and physical activity

Higher residential surrounding greenness in radiuses of 300 m and 500 m around the home residence is associated with an increase in odds of being more resistant to stress or fear during the COVID-19 pandemic (Fig. 3). For an IQR contrast in residential total green percentages in radiuses of 300 m and 500 m around the residence, participants were respectively 24% (OR = 1.24, 95%CI: 1.03 to 1.51) and 29% (OR = 1.29, 95%CI: 1.04 to 1.60) more likely to be in a more favourable category with respect to reported feelings stress and/or fear during the pandemic. In radiuses of 50 m and 100 m, the effect estimates were smaller, and not statistically significant (50 m: OR = 1.09, 95%CI: 0.91 to 1.31; 100 m: OR = 1.15, 95%CI: 0.94 to 1.41). For the largest radius (1000 m), we observed no association (OR = 1.11, 95%CI: 0.89 to 1.39). Overall, we found that the association with total green was stronger, as compared with the stratification in low (<3 m) and high (>3 m) green layers (Fig. 3).

The results did not differ after accounting for baseline stress at the time of recruitment using the Perceived Stress Scale scores (300 m: OR = 1.27, 95%CI: 1.02 to 1.58; 500 m: OR = 1.27, 95%CI: 1.00 to 1.62), changes in habits (with respect to diet, smoking behavior and alcohol consumption) during the pandemic (300 m: OR = 1.27, 95%CI: 1.04 to 1.54; 500 m: OR = 1.31, 95%CI: 1.05 to 1.62), previously diagnosed psychological disorders (300 m: OR = 1.24, 95%CI: 1.02 to 1.50; 500 m: OR = 1.28, 95%CI: 1.04 to 1.59), physical activity frequency at the time of recruitment (300 m: OR = 1.23, 95%CI: 1.01 to 1.50; 500 m: OR = 1.27, 95%CI: 1.03 to 1.58) or the reported number of packyears at the time of recruitment (300 m: OR = 1.26, 95%CI: 1.04 to 1.54; 500 m: OR = 1.32, 95%CI: 1.06 to 1.65) (Table 3).

We observed no significant increases in the odds of reporting more frequent participation in physical activities (long walks, cycling, jogging, …) during the pandemic than before the pandemic for an IQR contrast in green space exposure (Table 4).

4. Discussion

The key finding of our study was that residential green space in close proximity to the residence was associated with a buffering effect on stress levels during the COVID-19 pandemic, independent of socio-economic factors, baseline stress levels before the pandemic, and other covariates. Women with higher percentages of green space in proximity to their residence have significantly higher odds to be less affected by increased feelings of stress since the disease outbreak. This observation suggests a potential positive effect of green space proximity on general well-being during the pandemic. Therefore, our results reinforce

Table 2
Distribution of green space percentages in the different radiuses around the residence (50 m, 100 m, 300 m, 500 m, and 1000 m).

	Buffer size	*10th percentile*	*25th percentile*	Median	75th percentile	*90th percentile*	IQR
Total green	50 m	24.7%	34.6%	45.5%	56.1%	67.0%	32.4%
	100 m	30.0%	38.0%	47.8%	59.2%	67.4%	21.2%
	300 m	32.2%	40.5%	49.6%	59.6%	69.5%	19.2%
	500 m	31.5%	40.2%	50.6%	61.5%	69.4%	21.3%
	1000 m	30.9%	39.7%	52.2%	63.7%	71.4%	54.0%
High green (>3 m)	50 m	0.8%	2.8%	7.6%	16.4%	30.18%	13.6%
	100 m	3.4%	6.4%	10.5%	19.6%	34.0%	13.2%
	300 m	6.9%	9.7%	15.4%	26.7%	39.5%	17.0%
	500 m	8.3%	11.7%	19.1%	31.4%	42.4%	19.7%
	1000 m	10.1%	15.4%	24.9%	37.7%	47.84%	22.1%
Low green (<3 m)	50 m	16.5%	23.9%	33.2%	42.5%	50.34%	18.6%
	100 m	19.5%	26.3%	32.8%	40.3%	48.35%	14.0%
	300 m	19.1%	24.6%	30.4%	36.0%	42.0%	11.4%
	500 m	18.3%	22.4%	28.3%	33.1%	37.9%	10.7%
	1000 m	16.1%	20.1%	24.0%	27.7%	33.6%	7.6%

Abbreviations: IQR = inter-quartile range.

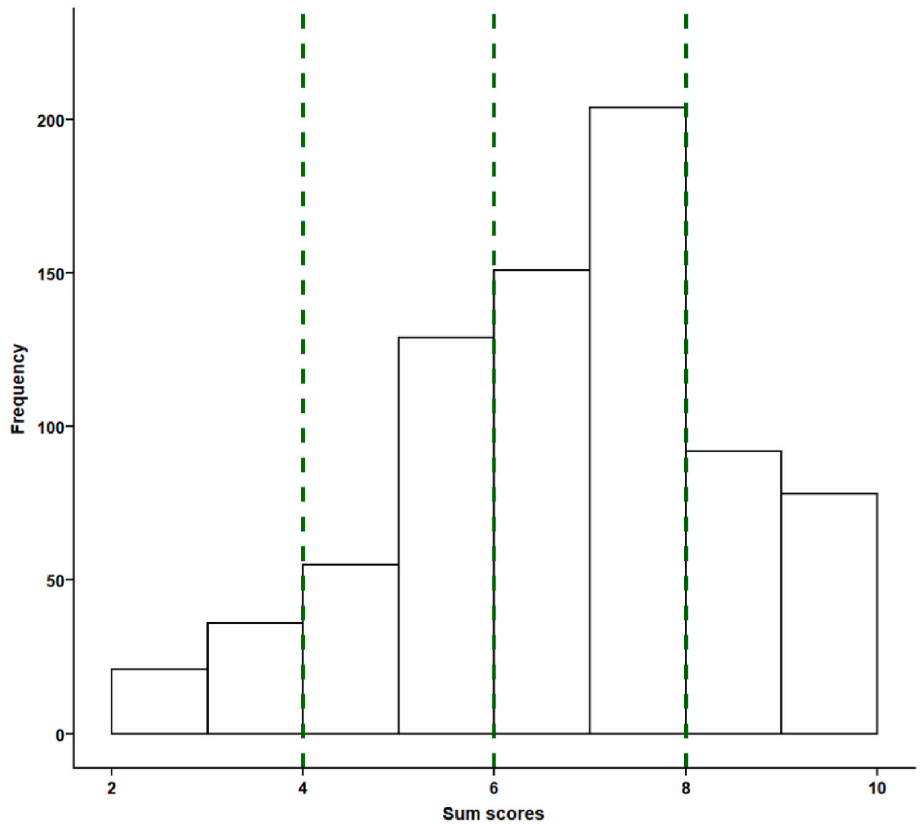


Fig. 2. Distribution of the total sum scores on the two indicator questions (COVID-19 related stress and fear for the future) for all participants. Higher scores indicate reporting increased feelings of stress and fear during the pandemic. The vertical dashed lines in green represent the cutoffs for the four categories. From left to right: highly resistant scores, high-to-medium resistance scores, medium-to-low resistance scores, and lowest resistance scores. n = 766.

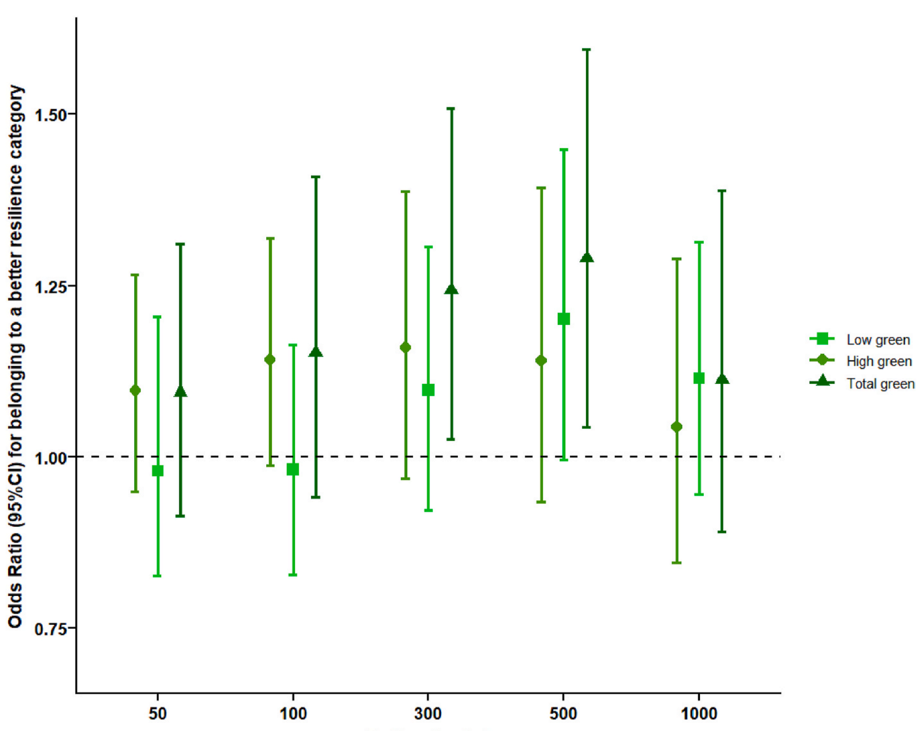


Fig. 3. Association between residential green space in buffers of several sizes around the residence (50m, 100m, 300m, 500m, and 1000m) and the Odds Ratios (with 95% CI) for belonging to a more favourable category of resistance to reported stress and fear responses during the pandemic, as determined by ordinal logistic regression. An Odds Ratio larger than 1 signifies being more likely to report lower levels of increased stress or fear for the future during the pandemic as compared to before the pandemic. The estimates represent the change in Odds Ratio for an IQR contrast in green space in the respective buffer (see Table 2). All models were adjusted for change in household monthly income, urbanicity, the participant's age, the highest attained degree and stress related to care for children. n = 766. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

potential benefits of protecting, maintaining and developing green areas as a way to support welbeing during psychologically challenging times. From the results of our study, it appears that green space in close proximity to the residence is more influential than green space in larger radiuses. This may have several underlying reasons: for example, more direct and frequent exposure to the visual and auditory elements of

Table 3
Sensitivity analyses on the association between residential green space in several buffers around the residence (50 m, 100 m, 300 m, 500 m, and 1000 m) and the odds of being resistant to increased stress and fears during the COVID-19 pandemic (n = 766*).

	Buffer	Odds Ratio (95% CI)	p-value
Main models	50 m	1.09 (0.91–1.31)	0.33
	100 m	1.15 (0.94–1.41)	0.17
	300 m	1.24 (1.03–1.51)	0.03
	500 m	1.29 (1.04–1.60)	0.02
	1000 m	1.11 (0.89–1.39)	0.35
Main models + Adjustment for baseline PSS scores* (time of recruitment)	50 m	1.12 (0.91–1.39)	0.28
	100 m	1.18 (0.94–1.48)	0.15
	300 m	1.27 (1.02–1.58)	0.03
	500 m	1.27 (1.00–1.62)	0.05
	1000 m	1.06 (0.82–1.37)	0.65
Main models + Adjustment for psychological disorders	50 m	1.09 (0.91–1.30)	0.37
	100 m	1.14 (0.93–1.40)	0.19
	300 m	1.24 (1.02–1.50)	0.03
	500 m	1.28 (1.04–1.59)	0.02
	1000 m	1.11 (0.89–1.38)	0.37
Main models + Adjustment for physical activity (time of recruitment)	50 m	1.08 (0.90–1.29)	0.39
	100 m	1.13 (0.92–1.39)	0.24
	300 m	1.23 (1.01–1.50)	0.04
	500 m	1.27 (1.03–1.58)	0.03
	1000 m	1.11 (0.88–1.39)	0.38
Main models + Adjustment for Smoking (pack-years, time of recruitment)	50 m	1.13 (0.89–1.29)	0.49
	100 m	1.13 (0.92–1.39)	0.24
	300 m	1.26 (1.04–1.54)	0.02
	500 m	1.32 (1.06–1.65)	0.01
	1000 m	1.14 (0.91–1.44)	0.25
Main models + Adjustment for changes in habits during the pandemic (diet, smoking, alcohol consumption)	50 m	1.12 (0.93–1.35)	0.22
	100 m	1.17 (0.96–1.44)	0.12
	300 m	1.27 (1.04–1.54)	0.02
	500 m	1.31 (1.05–1.62)	0.01
	1000 m	1.13 (0.90–1.42)	0.28
Main models + Adjustment for change in physical activity (during the pandemic)	50 m	1.11 (0.93–1.33)	0.26
	100 m	1.17 (0.95–1.43)	0.14
	300 m	1.25 (1.03–1.52)	0.02
	500 m	1.29 (1.04–1.60)	0.02
	1000 m	1.10 (0.88–1.38)	0.40
Main models + Adjustment for BMI (time of recruitment)	50 m	1.08 (0.90–1.30)	0.40
	100 m	1.14 (0.93–1.39)	0.22
	300 m	1.24 (1.04–1.53)	0.03
	500 m	1.29 (1.04–1.60)	0.02
	1000 m	1.11 (0.89–1.39)	0.37
Main models + All mentioned covariates.	50 m	1.16 (0.94–1.44)	0.17
	100 m	1.22 (0.96–1.56)	0.11
	300 m	1.36 (1.08–1.72)	0.01
	500 m	1.39 (1.07–1.80)	0.01
	1000 m	1.15 (0.88–1.52)	0.31

Estimates represent the change in Odds Ratio for an IQR increase in total green space in the respective buffer. All models were adjusted for change in monthly household income, the participant's age, the highest attained degree, and stress related to care for children. (*): PSS scores at the time of recruitment were available for 613 of the 766 participants.

green elements in close proximity to the home. Furthermore, during the pandemic, most people spent more time in and in the direct environment of their home, rather than in the broader neighborhood due to COVID-19 restrictions.

The link between mental well-being and nature has been established in recent years. Higher exposure to nature is positively associated with lower frequencies of intrusive thoughts, lower risk for serious psychological disorders such as major depressive disorder, and increases in general mental well-being (Beyer et al., 2014; Gascon et al., 2015, 2018; Bratman et al., 2019; Engemann et al., 2019; Sarkar et al., 2018). Underlying these observations are various potential mechanisms. Green spaces facilitate physical activity, social interaction and cohesion (Bratman et al., 2019; Weinstein et al., 2015; van den Berg et al., 2019; Wang et al., 2019). Furthermore, evidence suggests that there may be several biological factors (such as influences on human microbiota and neurological effects) that mediate the associations between green spaces and better health outcomes (Hanski et al., 2012; Bratman et al., 2015; Aerts et al., 2018). Underlying psychological factors may include associations between nature exposure, impulsivity and planning skills. Recent evidence demonstrates that lower levels of impulsivity and the ability to establish or adapt routines is related to resilience during the COVID-19 pandemic (Vicens et al., 2021; Morales-Vives et al., 2020), whereas higher exposure to nature is associated with lower levels of impulsive decision-making (Repke et al., 2018) which would be beneficial during challenging or uncertain times.

Table 4
Association between residential green space and the odds of reporting more frequent physical activities (long walks, cycling, jogging) during the pandemic than before the pandemic.

Buffer	Odds Ratio (95% CI)	p-value
50 m	0.94 (0.84–1.05)	0.25
100 m	0.92 (0.82–1.04)	0.19
300 m	0.99 (0.84–1.17)	0.91
500 m	1.01 (0.84–1.23)	0.90
1000 m	1.03 (0.84–1.26)	0.80

Estimates represent the change in Odds Ratio for an IQR increase in total green space in the respective buffer. All models were adjusted for change in monthly household income, the participant's age, the highest attained degree, and stress related to care for children.

Over the past year, researchers have investigated the connections between nature exposure during the pandemic and various health aspects. Some evidence suggests that exposure to green spaces are associated with lower incidence rates of COVID-19 infections (Klompmaker et al., 2021), and reduced mortality risks (Russette et al., 2021). Additionally, socially disadvantaged groups may benefit more from these effects, thereby helping to reduce social inequalities in health during the pandemic (Lu et al., 2021; Geary et al., 2021). At an aggregated level, citizens in countries where safety measures included reduced access to nature showed higher anxiety and depressive symptoms (Pouso et al., 2020). Frequency of visiting green spaces during the pandemic is associated with mental well-being (Hubbard et al., 2021; Robinson et al., 2021). Furthermore, self-reported indoor green features such as plant pots and sunlight and green view were associated with lower increases in (among others) anger, fear, irritibility and sleep disturbances during the pandemic (Spano et al., 2021). Similarly, students that report more green at home and in their neighborhood showed less depressive and anxiety symptoms during home isolation (Dzhambov et al., 2021). Finally, one study reported an association between green space (based on normalized difference vegetation index, NDVI) in a 250 m radius around the postcode and higher well-being scores (Robinson et al., 2021). Our finding that green spaces quantities in close proximity to the residence are associated with a stress buffering effect during the COVID-19 pandemic, are consistent with all of these results.

Our study has a several advantages. First, to our knowledge, this is the first study that has investigated the association between green spaces and mental health during the COVID-19 pandemic using a very high-resolution land cover map (1 m^2). Second, we prevented responder bias (i.e., the risk that participants guessed the intent of the questionnaire and give biased answers accordingly) by not revealing the intent of investigating the link between green space and health to the participants, and by including only a few questions related to green spaces. Third, we had prospective information on well-being before the pandemic so that we could account for baseline stress level. Such longitudinal information is important towards causal understanding. Lastly, we asked specifically for the participants feelings about stress during the pandemic, as compared to the situation before the outbreak, which allowed us to use an outcome measure of resistance to stress that was very specific to the pandemic situation. A downside of this approach is a lack of psychometric properties and external validation for this measurement. Additionally, our study also has limitations in its generalisability to the broader population, since the study included only mothers of young children. Furthermore, the municipalities within the geographical area (province of Limburg, Belgium) in which the study took place had a population density ranging between 82 and 743 inhabitants/km (Christina)Innes et al. (2021), which may not be representative for other areas around the world such as major cities with very high population densities, or remote and rural areas with low population densities. Lastly, our study cohort participants were on average more highly educated than the national average, which further limits the ability to generalize the results for the wider population.

5. Conclusion

The findings from this study highlight the importance of maintaining and developing green spaces as a way to maintain mental health, especially during psychologically challenging times.

Role of the funding source

This research is supported by the Flemish Scientific Fund N1518119 and G082317N.

Dries S. Martens holds a postdoctoral grant by the Flemish Scientific Fund (FWO grant 12X9620N).

Esmée M. Bijnens holds a fellowship from the Marguerite-Marie Delacroix foundation.

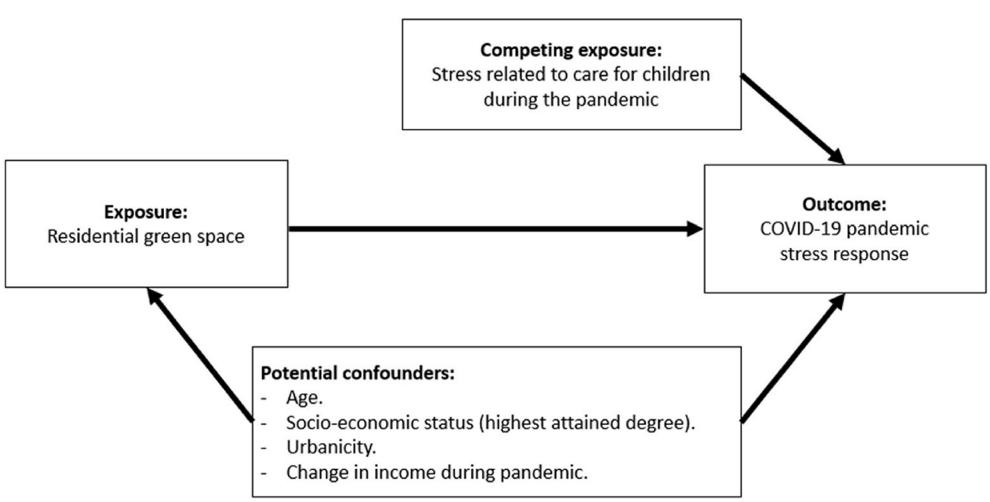
The funders of the study had no role in the study design, data collection, data analysis, data interpretation, or the writing of the report. All authors had full access to all the data in the study and had the final responsibility for the decision to submit the manuscript.

Approval by ethics committee

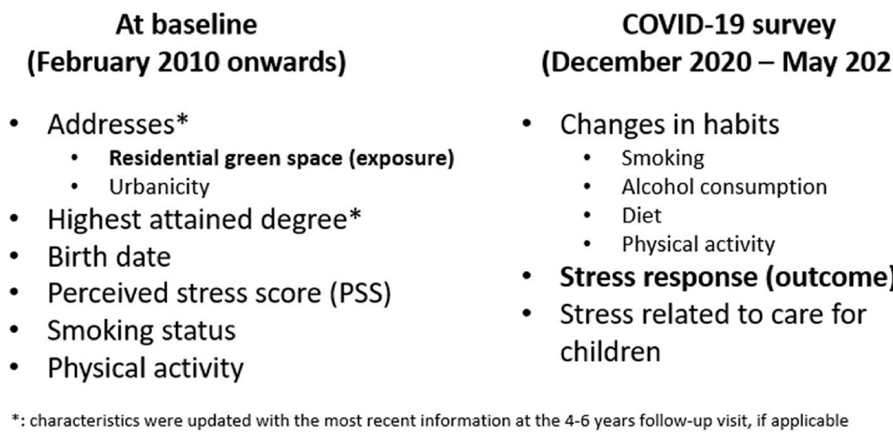
The Ethics Committee of Hasselt University and the East-Limburg Hospital approved the study protocol that was carried out following the Declaration of Helsinki. Written informed consent was obtained from all participating mothers.

Author contributions

Stijn Vos: Conceptualization, Methodology, Data collection, Formal analysis, Investigation, Writing – original draft, Esmée M. Bijnens: Software, Methodology, Writing – review & editing, Eleni Renaers: Data collection, Writing – review & editing, Hanne Croons: Data collection, Writing – review & editing, Charlotte Van Der Stukken: Data collection, Writing – review & editing, Dries S. Martens: Writing – review & editing, Michelle Plusquin: Writing – review & editing. Tim S. Nawrot: Methodology, Supervision, Resources, Funding acquisition, Writing – review



Supplemental Fig. 1. Directed acyclic graph representing the exposure, outcome, potential confounders and competing exposures included in the analyses.



Supplemental Fig. 2. Overview of the measures taken for this study at the different time points (at baseline/recruitment date, and during the COVID-19 survey).

& editing.

Supplemental Table 1
Changes in employment status or working conditions. Participants were asked to indicate which of the following applied to their situation at the time of the survey, or at any point during the COVID-19 pandemic (from March 2020 onwards).

Change in employment/working conditions	Number (%)
No changes in employment status or working conditions	298 (38.9%)
Temporary unemployment	123 (16.1%)
Unemployment	29 (3.8%)
Business closed	29 (3.8%)
New job	43 (5.6%)
Parental leave	83 (10.8%)
Working from home	294 (38.4%)

Data sharing statement

The data that were used for the analyses in this research article can be obtained from the authors upon request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank the participating women, as well as the staff of the maternity ward, midwives, and the staff of the clinical laboratory of East-Limburg Hospital in Genk.

References

Aerts, R., Honnay, O., Van Nieuwenhuyse, A., 2018. Biodiversity and Human Health: Mechanisms and Evidence of the Positive Health Effects of Diversity in Nature and Green Spaces. British Medical Bulletin.
Beyer, K.M.M., Kaltenbach, A., Szabo, A., Bogar, S., Javier Nieto, F., Malecki, K.M., 2014 Mar 21. Exposure to neighborhood green space and mental health: evidence from the survey of the health of Wisconsin. Int. J. Environ. Res. Publ. Health 11 (3), 3453–3472.
Bratman, G.N., Hamilton, J.P., Hahn, K.S., Daily, G.C., Gross, J.J., 2015. Nature experience reduces rumination and subgenual prefrontal cortex activation. Proc. Nat. Acad. Sci. U. S. A. 112 (28).
Bratman, G.N., Anderson, C.B., Berman, M.G., Cochran, B., de Vries, S., Flanders, J., et al., 2019. Nature and mental health: an ecosystem service perspective Science Advances. Am. Assoc. Adv. Sci. 55 (7).
Brooks, S.K., Webster, R.K., Smith, L.E., Woodland, L., Wessely, S., Greenberg, N., et al., 2020 Mar 14. The psychological impact of quarantine and how to reduce it: rapid review of the evidence. Lancet 395 (10227), 912–920.
Christina), Geng D (, Innes, J., Wu, W., Wang, G., 2021 Apr 1. Impacts of COVID-19 pandemic on urban park visitation: a global analysis. J. For. Res. 32 (2), 553–567.
Cohen, S., Kamarck, T., Mermelstein, R., 1983. A global measure of perceived stress. J. Health Soc. Behav. 24, 385–396. US: American Sociological Assn.
Dzhambov, A.M., Lercher, P., Browning, M.H.E.M., Stoyanov, D., Petrova, N., Novakov, S., et al., 2021 May 1. Does greenery experienced indoors and outdoors provide an escape and support mental health during the COVID-19 quarantine? Environ. Res. 196.
Engemann, K., Pedersen, C.B., Arge, L., Tsirogiannis, C., Mortensen, P.B., Svenning, J.C., 2019. Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. Proc. Nat. Acad. Sci. U. S. A. 116 (11).
Gascon, M., Mas, M.T., Martínez, D., Dadvand, P., Forns, J., Plasència, A., et al., 2015. Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. Int. J. Environ. Res. Publ. Health. MDPI AG 12, 4354–4379.
Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., et al., 2016. Residential Green Spaces and Mortality: A Systematic Review, vol. 86. Environment International. Elsevier Ltd, pp. 60–67.
Gascon, M., Sánchez-Benavides, G., Dadvand, P., Martínez, D., Gramunt, N., Gotsens, X., et al., 2018 Apr 1. Long-term exposure to residential green and blue spaces and anxiety and depression in adults: a cross-sectional study. Environ. Res. 162, 231–239.
Geary, R.S., Wheeler, B., Lovell, R., Jepson, R., Hunter, R., Rodgers, S., 2021. A call to action: improving urban green spaces to reduce health inequalities exacerbated by COVID-19. In: Preventive Medicine. Academic Press Inc., 145.
Hanski, I., Von Hertzen, L., Fyhrquist, N., Koskinen, K., Torppa, K., Laatikainen, T., et al., 2012. Environmental Biodiversity, Human Microbiota, and Allergy Are Interrelated. Proceedings of the National Acadamy of Sciences of the United States of America.
Henson, P., Pearson, J.F., Keshavan, M., Torous, J., 2020. Impact of dynamic greenspace exposure on symptomatology in individuals with schizophrenia. Publ. Libr. Sci. One 15 (9), e0238498.
Hubbard, G., Den Daas, C., Johnston, M., Murchie, P., Thompson, C.W., Dixon, D., 2021 Apr 2. Are rurality, area deprivation, access to outside space, and green space associated with mental health during the covid-19 pandemic? A cross sectional study (charis-e). Int. J. Environ. Res. Publ. Health 18 (8).
Janssen, B.G., Madhloum, N., Gyselaers, W., Bijnens, E., Clemente, D.B., Cox, B., et al., 2017 Oct 1. Cohort Profile: the ENVIRonmental influence ON early AGEing (ENVIRONAGE): a birth cohort study. Int. J. Epidemiol. 46 (5).
Ji, J.S., Zhu, A., Lv, Y., Shi, X., 2020 Mar. Interaction between residential greenness and air pollution mortality: analysis of the Chinese Longitudinal Healthy Longevity Survey. Lancet Planet. Health 4 (3), e107–e115.
Jimenez, M.P., Wellenius, G.A., James, P., Subramanian, S.V., Buka, S., Eaton, C., et al., 2020 Jun. Associations of types of green space across the life-course with blood pressure and body mass index. Environ. Res. 185.
Klompmaker, J.O., Hart, J.E., Holland, I., Sabath, M.B., Wu, X., Laden, F., et al., 2021 Aug. County-level exposures to greenness and associations with COVID-19 incidence and mortality in the United States. Environ. Res. 199, 111331.
Kondo, M.C., Fluehr, J.M., McKeon, T., Branas, C.C., 2018. Urban Green Space and its Impact on Human Health, vol. 15. International Journal of Environmental Research and Public Health. MDPI AG.
Leijdesdorff, S., van Doesum, K., Popma, A., Klaassen, R., van Amelsvoort, T., 2017 Jul. Prevalence of psychopathology in children of parents with mental illness and/or addiction: an up to date narrative review. Curr. Opin. Psychiatr. 30 (4), 312–317.
Lu, Y., Chen, L., Liu, X., Yang, Y., Sullivan, W.C., Xu, W., et al., 2021 Jul 1. Green spaces mitigate racial disparity of health: a higher ratio of green spaces indicates a lower racial disparity in SARS-CoV-2 infection rates in the USA. Environ. Int. 152.

Morales-Vives, F., Dueñas, J.-M., Vigil-Colet, A., Camarero-Figuerola, M., 2020. Psychological variables related to adaptation to the COVID-19 lockdown in Spain. Front. Psychol. 11, 2438.

Pierce, M., Hope, H.F., Kolade, A., Gellatly, J., Osam, C.S., Perchard, R., et al., 2020 Jul. Effects of parental mental illness on children's physical health: systematic review and meta-analysis. Britisch J. Psychiatr. 217 (1), 354–363.

Pouso, S., Borja, Á., Fleming, L.E., Gómez-Baggethun, E., White, M.P., Uyarra, M.C., 2020. Contact with Blue-Green Spaces during the COVID-19 Pandemic Lockdown Beneficial for Mental Health. Science of the Total Environment, p. 756.

Repke, M.A., Berry, M.S., Conway III, L.G., Metcalf, A., Hensen, R.M., Phelan, C., 2018 Aug 22. How does nature exposure make people healthier?: evidence for the role of impulsivity and expanded space perception. Publ. Libr. Sci. One 13 (8), e0202246.

Robinson, J.M., Brindley, P., Cameron, R., Maccarthy, D., Jorgensen, A., 2021 Mar 1. Nature's role in supporting health during the covid-19 pandemic: a geospatial and socioecological study. Int. J. Environ. Res. Publ. Health 18 (5), 1–21.

Roe, J., Thompson, C., Aspinall, P., Brewer, M., Duff, E., Miller, D., et al., 2013 Sep 2. Green space and stress: evidence from cortisol measures in deprived urban communities. Int. J. Environ. Res. Publ. Health 10 (9), 4086–4103.

Rojas-Rueda, D., Nieuwenhuijsen, M.J., Gascon, M., Perez-Leon, D., Mudu, P., 2019 Nov. Green spaces and mortality: a systematic review and meta-analysis of cohort studies. Lancet Planet. Health 3 (11), e469–e477.

Russette, H., Graham, J., Holden, Z., Semmens, E.O., Williams, E., Landguth, E.L., 2021 Jul 1. Greenspace exposure and COVID-19 mortality in the United States: january–july 2020. Environ. Res. 198.

Sarkar, C., Webster, C., Gallacher, J., 2018. Residential greenness and prevalence of major depressive disorders: a cross-sectional, observational, associational study of 94879adult UK Biobank participants. Lancet Planet. Health 2 (4).

Spano, G., D'Este, M., Giannico, V., Elia, M., Cassibba, R., Lafortezza, R., et al., 2021 Jul. Association between Indoor-Outdoor Green Features and Psychological Health during the COVID-19 Lockdown in Italy: A Cross-Sectional Nationwide Study, vol. 62. Urban For Urban Green, p. 127156.

van den Berg, M.M., van Poppel, M., van Kamp, I., Ruijsbroek, A., Triguero-Mas, M., Gidlow, C., et al., 2019 Feb 1. Do physical activity, social cohesion, and loneliness mediate the association between time spent visiting green space and mental health? Environ. Behav. 51 (2), 144–166.

Vicens, P., Heredia, L., Bustamante, E., Pérez, Y., Domingo, J.L., Torrente, M., 2021 Mar 17. Does living close to a petrochemical complex increase the adverse psychological effects of the COVID-19 lockdown? Publ. Libr. Sci. One 16 (3), e0249058.

Volenec, Z.M., Abraham, J.O., Becker, A.D., Dobson, A.P., 2021 May 19. Public parks and the pandemic: how park usage has been affected by COVID-19 policies. In: Lepczyk, C.A. (Ed.), Public Library of Science One, vol. 16, e0251799, 5.

Wang, H., Dai, X., Wu, J., Wu, X., Nie, X., 2019 Aug 13. Influence of urban green open space on residents' physical activity in China. BMC Publ. Health 19 (1).

Weinstein, N., Balmford, A., Dehaan, C.R., Gladwell, V., Bradbury, R.B., Amano, T., 2015. Seeing community for the trees: the links among contact with natural environments, community cohesion, and crime. Bioscience 65 (12).

Wolicki, S.B., Bitsko, R.H., Cree, R.A., Danielson, M.L., Ko, J.Y., Warner, L., et al., 2021. Mental health of parents and primary caregivers by sex and associated child health indicators. Adv. Resil. Sci. 2 (2), 125–139.