

Review Article

The Effect of Natural Environment on Preventing Depression among Children and Adolescents

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Abstract

Green spaces have been associated with a wide range of health benefits in adults, including mental health; however, there are relatively limited data about the relationship between exposure to natural environment and children's and adolescents' mental health, and particularly depression. The aim of this review was to synthesise and discuss the literature regarding the effect of the natural environment on preventing depression among children and adolescents and also to identify potential mediating factors. Based on most studies, exposure to green spaces, especially in urban environments, was shown to contribute to the prevention of depression among children and adolescents. Specifically, increased exposure to greenery was shown to reduce by 6% to 11% the risk of depression in children and adolescents, and this association was more powerful in urban areas with higher population density. High levels of exposure to green spaces during childhood were also significantly associated with a lower risk of depression in later life with the risk of subsequent mental illness for individuals who lived in areas with low levels of greenery during childhood being 55% higher than for those who lived in areas with higher green coverage. However, above associations were not confirmed across studies, and findings regarding potential mediating factors were inconsistent. This review has shown high heterogeneity of the identified studies, using different samples, both in size, age and participants' characteristics, different outcome measures and different tools for estimating outcome measures. Further research is needed to investigate the impact of the natural environment on preventing depression in the case of children and adolescents, while future studies need to utilize similar participant criteria and common outcome measures and instruments, to allow for comparison of the findings.

Keywords: natural environment, nature, green spaces, depression, children, adolescents

Introduction

Exposure to natural environments, including both green spaces (trees, grass, etc.) and blue spaces (rivers, lakes, etc.), appears to provide significant health benefits, particularly for people's mental health (Silva, Rogers and Bugley, 2018; Helbich et al., 2019; Perrino et al., 2019). The terms 'nature' and 'natural environment' refer to spaces where most ecosystem processes are present, including habitats, ranging from wildlife environments to parks and gardens in urban settings (Snell et al., 2016). Time spent in nature, can provide significant benefits to physical health, and also to mental health and well-being of middle-aged and older adults (South et al., 2018; Abraham Cottagiri et al., 2022). Spending time in nature appears to significantly improve an individual's responses to psychological and physiological stress, facilitate social interaction, restore attention and encourage physical activity, all being means of improving mental health (Nieuwenhuijsen et al., 2017; Fong, Hart and James, 2018). Furthermore, adults' living in urban areas is associated with an increased risk of serious mental disorders compared to people living in rural areas; in specific, urban residents show significantly higher rates of depression, post-traumatic stress disorder, schizophrenia, paranoia and distress (Buttazzoni et al., 2022).

In this context, research has largely focused today on the impact of nature on various aspects of mental health, such as mental resilience, general psychiatric morbidity, anxiety and depression (South et al., 2021). However, findings across different studies are inconsistent and while some studies show positive relationship between exposure to the environment and mental health, others have reported a non-statistical association between the two (Alcock et al., 2015; de Bell et al., 2017; Helbich et al., 2019). Regarding depression, a leading cause of disability globally (Friedrich, 2017), according to a large population-based cross-sectional study, visiting green spaces for 30 minutes per week reduces the prevalence of depression in the general population by 7% (Shanahan et al.,

2016; South et al., 2021). At the same time, the presence of green space in neighbourhoods leads to lower levels of depression in residents of these areas, while a significant reduction in depression rates has been observed among older people living in retirement homes in neighbourhoods with more trees (Browning, Lee and Wolf, 2019; Nishigaki et al., 2020; South et al., 2021). Furthermore, the link between nature and mental health became particularly evident during the COVID-19 pandemic, as those restricted from going outdoors experienced the highest levels of anxiety and depression (Young et al., 2022).

The mechanisms through which green spaces can influence depression and neuro-behavioural problems in general are numerous and include, among others, the following: increasing physical activity, relieving mental fatigue and anxiety/stress, fostering social interactions and facilitating social ties (Cohen-Cline, Turkheimer and Duncan, 2015). For example, regular physical activity is associated with lower symptoms of depression and anxiety, while walking in nature may benefit the mental health of adults to a greater extent than walking in urban environments with results being significant among adult individuals with depression (Watkins-Martin et al., 2022). It is worth noting that although there has been considerable research in recent years on the benefit of green exposure on depression in adults, the research on exposure to blue spaces is much limited, although there are indications for their possible benefit for wellbeing, including depression (Gascon et al., 2015; Dempsey et al., 2018). School-aged children often experience high levels of stress, anxiety, depression, and mental health problems (Bang et al., 2018) while in adolescence, the most common mental health disorders are anxiety and depression, with a prevalence of 30% and 13%, respectively (Hartley et al., 2021).

Nature has shown to help children improve their psychological functioning, think more clearly, cope with their problems, and feel relaxed and free (Corraliza, Collado and Bethelmy, 2012; Bang et al., 2018). Time spent in nature or viewing the natural

environment from classroom windows can significantly improve students' perceived stress and fatigue levels (Lee and Sullivan, 2016; Lindemann-Matthies et al., 2021). Many researchers argue that contact with nature during childhood is essential for healthy development due to the fact that green spaces enable physical exercise, promote identity construction, provide a context for learning about the world, and reduce stress levels, benefits which continue into an adult life (Snell et al., 2016). The presence of greenery in neighborhoods has shown to comprise a protective factor for the development of behavioral externalization problems among adolescents (Weeland et al., 2019). In a systematic review (Vanaken and Danckaerts, 2018), a beneficial association was found between green exposure and children's behavioral and emotional difficulties, particularly in attention and hyperactivity problems. Similarly, another review (Zhang et al., 2020) examining the association between green spaces and mental wellbeing of adolescents, found significant beneficial effects of exposure to greenery on mood, stress, depressive symptoms, psychological distress, mental health, emotional wellbeing and behavior.

Nevertheless, although green spaces have been associated with a wide range of health benefits in adults, there are relatively limited findings regarding the relationship between exposure to nature and green spaces, and children's and adolescents' mental health, particularly the prevention of depression (Gascon et al., 2015). However, the effects of the natural environment on people's health, and in particular on depression, can vary significantly between different age groups (Zhou et al., 2022). Furthermore, an individual's exposure to nature during childhood and adolescence might affect the development of depression in adulthood (Snell et al., 2016). In this context, the aim of this review was to synthesise and discuss the literature published in English between 2017-2023, concerning the effect of the exposure of children and adolescents to the natural environment on preventing depression as well as potential mediating factors between exposure to nature and depression for this age group.

Exposure to green spaces and depression

Children and adolescents with higher exposure to green spaces had a 6% lower incidence of major depression symptoms, and this relationship was stronger in areas with higher population density; hence, living in an area with a greater amount of green space during childhood may be particularly beneficial for the mental health of these individuals, especially in more urbanized areas (Bezold et al., 2018b). Meanwhile, in a sample of adolescents aged 12- 18 years, an interquartile increase in green space scoring at a distance of 1250m was associated with an 11% lower likelihood of developing symptoms of major depression. This association was slightly higher in middle school students compared to high school students; however, this difference was not statistically significant (Bezold et al., 2018a). The statistically significant association between increased exposure to greenery, the presence of native vegetation, or a higher rate of exposure to nature and reduced depressive symptoms in adolescents was confirmed in another study (Mavoa et al., 2019).

A reduction in children's behavioral problems was observed in a study (Liao et al., 2020) to be associated with exposure to greenery around the kindergarten and with balanced exposure to greenery at home and the kindergarten. Specifically, a one inter-quartile range increase in the green exposure score around kindergarten and in the green exposure score after balancing for kindergarten and residential exposure was associated with reduced overall behavior scores, but also with a reduced risk of developing depression, anxiety, aggressive behavior, and hyperactivity and attention deficit disorder.

The presence of greenery around children's homes did not appear to be associated in statistically significant degree with self-reported symptoms of depression and anxiety in 12-year-old children, with the exception of the separation-related anxiety scale, which was significantly associated with the presence of greenery at 400 and 800 meters from the children's home (Hartley et al., 2021).

Therefore, in this study, no direct relationship was observed between greenery and overall symptoms of depression and anxiety in adolescents; however, the presence of greenery at distances 400 and 800 meters from home appeared to reduce separation anxiety symptoms for the 12 year olds.

However, according to another study (Lin et al., 2022), adolescents living in an urban area and attending urban schools tend to have significantly lower rates of depression, stress and anxiety than adolescents living in rural areas and attending urban schools or adolescents living in rural areas and attending rural schools. At the same time, depression was significantly and strongly associated with adolescent executive dysfunction, and among adolescents with depression, those living in urban settings and attending urban schools have a higher risk of executive dysfunction compared to adolescents living in rural areas and attending rural schools (Lin et al., 2022).

Other studies showed no direct and statistically significant relationship between exposure to greenery and overall depressive symptoms in adolescents (Hartley et al., 2021), or between higher percentages of green spaces in schools, or in neighborhood park areas, and children's symptoms of depression or anxiety (Sajady et al., 2020; Naya et al., 2022). For example, higher percentages of shrubs, grass, and trees in schools were not shown to be associated with externalizing and internalizing behaviors, including depression, in fifth-grade students (Sajady et al., 2020).

An intervention including lectures to promote physical and psychosocial health and activities in urban forests specifically designed for children was shown to result in significant reduction in depressive symptoms and improvement in self-esteem in elementary school children in vulnerable populations (Bang et al., 2018). In contrast, engagement with nature in the context of a school-based intervention that included hydroponic planting combined with health promotion activities, was not effective in significantly improving depression levels in early adolescent students (Kwok et al., 2021). However, a significant positive effect on adolescents' mental health was found in engaging them in home gardening activities; in particular, depression symptom levels were

reduced and mental well-being was promoted among adolescent students who were involved in these activities (van Lier et al., 2017). The indirect relationship between depression and nature-based intervention was examined by a recent study (Sobko et al., 2020), which involved 54 preschool children in a 10-week structured nature-related 'Play & Grow' program and found that children were significantly more connected to nature after the intervention while their gut microbiota altered, especially by modulating the abundance of Roseburia and the fecal-serotonin level, while reduction in the overall perceived stress was also noted among these children. These findings are important and need further attention, as the metabolic by-products of gut microbiota, shortchain fatty acids, are found to have a potential contribution to depression phenotype.

Literature has also examined the effect of childhood exposure to nature on the development of depression in adult life. Exposure to greenery, and in particular to domestic green spaces during childhood, has shown to have direct and indirect effects on contact with nature, connection to nature, and mental well-being and health in adulthood (Li et al., 2022).

Furthermore, urbanization during childhood appears to be significantly associated with the onset of depression in late adulthood, particularly evident for individuals who spent their childhood in semi-urban areas as they showed a 3.4 average increase in the risk of reporting 4 or more symptoms of depression after the age of 50 years (Howdon, Mieran and Liew, 2019).

According to a similar study (Engemann et al., 2019), high levels of exposure to greenery during childhood were also significantly associated with a lower risk of developing depression and other psychiatric disorders in later life, and this significant association remained even after adjusting for different socio-demographic characteristics. In particular, it was shown that the risk of subsequent mental illness for individuals who lived in areas with low green cover during childhood was 55% higher in comparison to those who lived in areas with higher green coverage.

Mediating factors between exposure to natural environment and depression

Both the quality and quantity of green spaces appear to be significantly related to children's well-being and to externalizing and internalizing problems, including depression (Feng and Astell-Burt, 2017). The relationship between green space quality and depression appears to be mediated by specific personality traits, such as introversion or neuroticism, but this was only observed in females; in specific, among adolescent girls, green space quality was associated with a decrease in mean internalizing problem scores and higher levels of introversion or neuroticism, whereas among male adolescents, green space quality did not affect the associations between neuroticism, introversion, and internalizing scores at all (Feng et al., 2022). The relation detected in the literature between urban living and semi-urban living during childhood and development of depression in later life (Howdon, Mieran and Liew, 2019), appeared to differ based on exposure to different kinds of green spaces and was stronger in women than in men, while the associations between exposure of preschoolers to greenery in kindergarten and reduction of behavioral problems, including a reduced risk of depression, were stronger among boys than girls (Liao et al., 2020). The concentration of nature was significantly and negatively associated with adolescents' depression and overall mood in another study (Li et al., 2018); however, this relationship was not found to be mediated by demographic and socioeconomic characteristics of adolescents.

In a later study (Madzia et al., 2019), the prevention of depression was significantly associated with exposure to green spaces only in the case of children aged 12 years and not in the 7 year olds' age group. This finding suggests that age may be a mediating factor in the relationship between green space and depression, and it is possible that the inconsistencies between different studies are due to the different age distribution of children and adolescents in the sample they evaluated.

The percentage of green spaces was found in a recent study (Zhang et al., 2022) to have a significant negative effect on adolescents'

emotional well-being and inconsistent impacts regarding the development of depression, while the effect on mental well-being and depression differed according to the distance between green spaces and adolescents' residence. Depressive symptoms and emotional well-being were more strongly related to other individual and neighborhood factors (e.g., neighborhood deprivation). However, it is worth noting that after adjusting for control variables, no statistically significant associations were observed between green space and the presence of depressive symptoms or the emotional well-being of adolescents in this study.

Bray et al. (2021) in their 20-year literature search (2000-2020) on whether exposure to green and blue spaces could reduce the risk of developing anxiety and depression in young people aged 14-24 years living in urban environments, found that the presence of natural environment or walking or living in green spaces could improve mood and temporary anxiety while the relationship between green exposure and mental health appeared to be mediated by mindfulness, physical activity and social interaction. Authors conclude that the absence of noise and the restorative qualities of green spaces promote mindfulness and interrupt rumination, which in turn decrease the risk of anxiety disorders and depression.

Discussion and conclusions

Childhood and adolescence are critical periods for human development and growth, and mental illness among young people can occur as a result of various physical, social and emotional contributing factors, including exposure to natural environment (Buttazzoni et al., 2022). In this context, particularly increased interest has recently emerged about the effects of green spaces on the mental health of children and adolescents (Snell et al., 2016). Studies showed a significant association between increased exposure to greenery and the prevention of depression. Specifically, increased exposure to greenery can reduce by 6% to 11% the risk of developing depression in children and adolescents, and this association is strongest in urban areas with higher population density (Bezold et al., 2018a, 2018b; Mavoia et al., 2019). Even a one inter-quartile range

increase in green exposure scores around kindergarten was associated, according to another study, with a reduced risk of developing depression, and this association was stronger among boys than girls (Liao et al., 2020).

A paradoxical finding is that adolescents living in an urban area and attending urban schools tend to have significantly lower rates of depression than adolescents living in rural areas and attending urban schools or adolescents living in rural areas and attending rural schools (Lin et al., 2022). Considering that in rural areas, adolescents are exposed more frequently and more to the natural environment, one would expect that adolescents living in rural areas and attending schools in rural areas would have lower levels of depression, an assumption that is in stark contrast to the findings of the Lin et al. (2022) study.

However, growing up in an area with a greater percentage of greenery can be particularly beneficial for the mental health of these individuals, especially in more urbanized regions, and this positive effect can be observed both in childhood and adolescence, as well as in later adult life (Bezold et al., 2018b). Childhood urbanization has been significantly associated with the onset of depression in late adulthood, and the association between urban and semiurban life appeared to be stronger in women than in men (Howdon, Mieran and Liew, 2019). High levels of exposure to greenery during childhood were also significantly associated with a lower risk of developing depression in later life, while the risk of subsequent mental illness for individuals who lived in areas with low levels of greenery during childhood was 55% higher than those who lived in areas with higher green coverage (Engemann et al., 2019).

However, while the link between exposure to nature or green environments and mental health has been explored in the case of adult population, relatively few studies examine the association between green spaces and depression in the case of children and adolescents. This knowledge gap is significant given the severe effects and the relatively high prevalence of depression in childhood and adolescence, as well as the

potential ability of green exposure to contribute to its prevention. Green exposure is a relatively easy and affordable solution that could be incorporated into interventions to prevent depression, or other mental and behavioural problems in children and adolescents, so it is very important to demonstrate any strong association between the positive effects of nature exposure on the prevention of mental health problems, including depression (Liao et al., 2020). The results of studies assessing the role of nature-based interventions to reducing depressive symptoms in children and adolescents, included in this review, are promising (van Lier et al., 2017; Bang et al., 2018). Concurrently, a key challenge in this research field is to disentangle the independent role of green exposure from other confounding variables, such as various demographic and socioeconomic factors (Vanaken and Danckaerts, 2018; Bray et al., 2021).

It could be possible that the association between exposure to nature during childhood and adolescence and depression might be related with the structural and functional changes that occur in the brain during this critical period of development (Snell et al., 2016; Bezold et al., 2018b), an assumption which needs to be clarified with further targeted research. This review has also shown high heterogeneity of the identified studies, where different samples, both in size, age and participants' characteristics, different outcome measures and different tools for estimating outcome measures were used. These differences could lead to inconsistencies in the findings of individual studies, even between those that focused on exactly the same objective. For example, depression was measured with a variety of tools in different studies, including Childhood Behavioral Checklist (Liao et al., 2020), Depression Anxiety & Stress Scale - 21 (DASS - 21) (Lin et al., 2022), Depression Inventory 2 (Bang et al., 2018; Hartley et al., 2021), or Reynolds Adolescents Depression Scale -Short Form (van Lier et al., 2017; Mavoia et al., 2019; Zhang et al., 2022). The way of defining and measuring exposure to the natural environment also varied considerably in different studies, a concern already identified in the relevant literature (Taylor and Hochuli, 2017). Therefore, in one

study (Bezold et al., 2018b), the natural environment was considered as the exposure to greenery, which was defined as the cumulative average of the Normalized Difference Vegetation Index (NDVI) (at 1000m) from 1989 to 2 years prior to the assessment, while in another study (Bezold et al., 2018a), exposure to greenery was assessed using NDVI at distances of 250m and 1250m. Liao et al. (2020) assessed the NDVI in a 100m circular protection zone around the central point of the homes and nurseries of the preschool children in their sample, and subsequently calculated weighted exposure to greenery based on the assumption that children spent 8h of their day at the nursery and 16h at home. In the study of Sajady et al. (2020), landscape data were collected through a geographic information system and percentages of grass, tree and shrub cover and impervious surfaces were calculated in 300 m and 500 m radius areas around each school building, while all participants in the study of Li et al. (2018) carried a GPS (Global Positioning System) device for 4 consecutive days, and their exposure to greenery was calculated by estimating Google Street View images at the locations found during the day. As the effect of nature on depression appears to differ according to the distance between the presence of green spaces and adolescents' residence (Zhang et al., 2022), this fact might also account for inconsistent findings across studies which measure exposure to natural environments based on different tools and distance calculations. Therefore, it is recommended that future studies attempting to investigate the impact of the natural environment on the development of depression, particularly among children/adolescents, utilize similar participant criteria, common outcome measures and instruments, to allow for more direct comparison of the resulting findings.

High heterogeneity was also observed in the factors examined as possible mediators in the relationship between exposure to the natural environment and depression. Personality characteristics, age and sex that were identified as mediating factors in some studies (Madzia et al., 2019; Feng et al., 2022), were not confirmed in others (Li et al., 2018). Further, mediating factors identified in adult studies, such as particulate matter or

suspended particles (Zhang et al., 2022a), physical exercise, sunlight, and neighborhood proximity (Wang et al., 2019), have not yet been examined in childhood and adolescence, so they could be variables to be considered in future studies. Appropriate individual and environmental control variables should be taken into consideration in future studies exploring the green spaces - mental wellbeing relationship in children and adolescents (Zhang et al., 2022).

Moreover, while it is known that children with various disorders, such as autism spectrum disorder, experience the mental health benefits of nature differently compared to typically developing children (Larson et al., 2018), no studies examining the effects of nature on depressive symptoms in the case of children and adolescents with neurodevelopmental disorders have been identified. It might thus be important to conduct primary studies to examine the impact of nature exposure in different populations of children, on their mental health, and particularly on depressive symptoms.

Finally, it is worth noting that there is a deficiency of relevant studies in Europe, particularly in Greece. Therefore, more research is encouraged in European countries, to determine if the trend of linking exposure to the natural environment with depression prevention holds true or varies across different regions.

This review suggests that exposure to green spaces, especially in urban environments, contributes to the prevention of depression among children and adolescents. Thus, incorporating exposure to nature into various health promotion interventions and programs is recommended. Expanding green spaces in urban areas and schools, where children and adolescents spend a significant part of their day, could be beneficial. Additionally, specific interventions with increased exposure to green spaces could be designed for children and adolescents who are at high risk of developing depression or those already experiencing symptoms. Overall, according to this review, exposure to the natural environment, and especially to greenery in urban environments, contributes to the prevention of depression among children and adolescents. Nevertheless, this relationship

was not confirmed in all studies, and potential mediating factors were inconsistent. Further research is needed to explore the environment's role as a protective factor against depression in children and adolescents.

References

- Abraham Cottagiri, S., Villeneuve, P.J., Raina, P., Griffith, L. E., Rainham, D., Dales, R., Peters, C. E., Ross, N. A. and Crouse, D. L. (2022). Increased urban greenness associated with improved mental health among middle-aged and older adults of the Canadian Longitudinal Study on Aging (CLSA). *Environmental Research*, 206: 112587. <https://doi.org/doi:10.1016/j.envres.2021.112587>
- Alcock, I., White, M. P., Lovell, R., Higgins, S. L., Osborne, N. J., Husk, K. and Wheeler, B. W. (2015). What accounts for "England's green and pleasant land"? A panel data analysis of mental health and land cover types in rural England. *Landscape and Urban Planning*, 142: 38–46. <https://doi.org/10.1016/j.landurbplan.2015.05.008>
- Bang, K.-S., Kim, S., Song, M. K., Kang, K. I. and Jeong, Y. (2018). The Effects of a Health Promotion Program Using Urban Forests and Nursing Student Mentors on the Perceived and Psychological Health of Elementary School Children in Vulnerable Populations. *International Journal of Environmental Research and Public Health*, 15(9): 1977. <https://doi.org/10.3390/ijerph15091977>
- de Bell, S., Graham, H., Jarvis, S. and White, P. (2017). The importance of nature in mediating social and psychological benefits associated with visits to freshwater blue space. *Landscape and Urban Planning*, 167: 118–127. <https://doi.org/10.1016/j.landurbplan.2017.06.003>
- Bezold, C. P., Banay, R. F., Coull, B. A., Hart, J. E., James, P., Kubzansky, L. D., Missmer, S. A. and Laden, F. (2018a). The Association Between Natural Environments and Depressive Symptoms in Adolescents Living in the United States. *The Journal of Adolescent Health: Official Publication of the Society for Adolescent Medicine*, 62(4): 488–495. <https://doi.org/10.1016/j.jadohealth.2017.10.008>
- Bezold, C. P., Banay, R. F., Coull, B. A., Hart, J. E., James, P., Kubzansky, L. D., Missmer, S. A. and Laden, F. (2018b). The relationship between surrounding greenness in childhood and adolescence and depressive symptoms in adolescence and early adulthood. *Annals of Epidemiology*, 28(4): 213–219. <https://doi.org/10.1016/j.annepidem.2018.01.009>
- Bray, I., Reece, R., Sinnett, D., Martin, F. and Hayward, R. (2022). Exploring the role of exposure to green space in preventing anxiety and depression among young people aged 14–24 living in urban settings: a systematic review. *Environmental Research*, 214(Pt 4):114081. <https://doi.org/10.1016/j.envres.2022.114081>
- Browning, M. H. E. M., Lee, K. and Wolf, K. L. (2019). Tree cover shows an inverse relationship with depressive symptoms in elderly residents living in U.S. nursing homes. *Urban Forestry & Urban Greening*, 41: 23–32. <https://doi.org/10.1016/j.ufug.2019.03.002>
- Buttazzoni, A., Doherty, S. and Minaker, L. (2022). How Do Urban Environments Affect Young People's Mental Health? A Novel Conceptual Framework to Bridge Public Health, Planning, and Neighbourhood. *Public Health Reports*, 137(1) : 48–61. <https://doi.org/10.1177/0033354920982088>
- Cohen-Cline, H., Turkheimer, E. and Duncan, G. E. (2015). Access to green space, physical activity and mental health: a twin study. *Journal of Epidemiology and Community Health*, 69(6): 523–529. <https://doi.org/10.1136/jech-2014-204667>
- Corraliza, J. A., Collado, S. and Bethelmy, L. (2012). Nature as a Moderator of Stress in Urban Children. *Procedia - Social and Behavioral Sciences*, 38: 253–263. <https://doi.org/10.1016/j.sbspro.2012.03.347>
- Dempsey, S., Devine, M. T., Gillespie, T., Lyons, S. and Nolan, A. (2018). Coastal blue space and depression in older adults. *Health & Place*, 54: 110–117. <https://doi.org/10.1016/j.healthplace.2018.09.002>
- Engemann, K., Pedersen, C. B., Arge, L., Tsirogiannis, C., Mortensen, P. B. and Svaning, J.C. (2019). Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. *Proceedings of the National Academy of Sciences*, 116(11): 5188–5193. <https://doi.org/10.1073/pnas.1807504116>
- Feng, X. and Astell-Burt, T. (2017). Residential Green Space Quantity and Quality and Child Well-being: A Longitudinal Study. *American Journal of Preventive Medicine*, 53(5): 616–624. <https://doi.org/10.1016/j.amepre.2017.06.035>
- Feng, X., Astell-Burt, T., Standl, M., Flexeder, C., Heinrich, J. and Markevych, I. (2022). Green space quality and adolescent mental health: do personality traits matter? *Environmental Research*, 206: 112591. <https://doi.org/10.1016/j.envres.2021.112591>

- Fong, K. C., Hart, J. E. and James, P. (2018). A Review of Epidemiologic Studies on Greenness and Health: Updated Literature Through 2017. *Current Environmental Health Reports*, 5(1): 77–87. <https://doi.org/10.1007/s40572-018-0179-y>
- Friedrich, M. (2017). Depression Is the Leading Cause of Disability Around the World. *JAMA*. 317(15):1517. <https://doi.org/doi:10.1001/jama.2017.3826>
- Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Forn, J., Plasència, A. and Nieuwenhuijsen, M. J. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. *International Journal of Environmental Research and Public Health*, 12(4): 4354–4379. <https://doi.org/10.3390/ijerph120404354>
- Hartley, K., Perazzo, J., Brokamp, C., Gillespie, G. L., Cecil, K. M., LeMasters, G., Yolton, K. and Ryan, P. (2021). Residential surrounding greenness and self-reported symptoms of anxiety and depression in adolescents. *Environmental Research*, 194: 110628. <https://doi.org/10.1016/j.envres.2020.110628>
- Helbich, M., Yao, Y., Liu, Y., Zhang, J., Liu, P. and Wang, R. (2019). Using deep learning to examine street view green and blue spaces and their associations with geriatric depression in Beijing, China. *Environment International*, 126: 107–117. <https://doi.org/10.1016/j.envint.2019.02.013>
- Howdon, D., Mierau, J. and Liew, S. (2019). The relationship between early life urbanicity and depression in late adulthood: evidence from the Survey of Health, Ageing and Retirement in Europe. *BMJ Open*, 9(9): e028090. <https://doi.org/10.1136/bmjopen-2018-028090>
- Kwok, S. W. H., Wu, C. S. T., Tong, H. T., Ho, C. N., Leung, K. L., Leung, Y. C. P., Lui, K. C. and Wong, C. K. C. (2021). Effects of the School-Based Integrated Health Promotion Program With Hydroponic Planting on Green Space Use and Satisfaction, Dietary Habits, and Mental Health in Early Adolescent Students: A Feasibility Quasi-Experiment. *Frontiers in Public Health*, 9: 740102. <https://doi.org/10.3389/fpubh.2021.740102>
- Larson, L. R., Barger, B., Ogletree, S., Torquati, J., Rosenberg, S., Gaither, C. J., Bartz, J. M., Gardner, A., Moody, E. and Schutte, A. (2018). Gray space and green space proximity associated with higher anxiety in youth with autism. *Health & Place*, 53: 94–102. <https://doi.org/10.1016/j.healthplace.2018.07.006>
- Li, D., Deal, B., Zhou, X., Slavenas, M. and Sullivan, W. C. (2018). Moving beyond the neighborhood: Daily exposure to nature and adolescents' mood. *Landscape and Urban Planning*, 173: 33–43. <https://doi.org/10.1016/j.landurbplan.2018.01.009>
- Li, D. and Sullivan, W. C. (2016). Impact of views to school landscapes on recovery from stress and mental fatigue. *Landscape and Urban Planning*, 148: 149–158. <https://doi.org/10.1016/j.landurbplan.2015.12.015>
- Li, H., Browning, M. H. E. M., Cao, Y. and Zhang, G. (2022). From Childhood Residential Green space to Adult Mental Wellbeing: A Pathway Analysis among Chinese Adults. *Behavioral Sciences (Basel)*, 12(3): 84. <https://doi.org/10.3390/bs12030084>
- Liao, J., Yang, S., Xia, W., Peng, A., Zhao, J., Li, Y., Zhang, Y., Qian, Z., Vaughn, M. G., Schootman, M., Zhang, B. and Xu, S. (2020). Associations of exposure to green space with problem behaviours in preschool-aged children. *International Journal of Epidemiology*, 49(3): 944–953. <https://doi.org/10.1093/ije/dyz243>
- van Lier, L. E., Utter, J., Denny, S., Lucassen, M., Dyson, B. and Clark, T. (2017). Home Gardening and the Health and Well-Being of Adolescents. *Health Promotion Practice*, 18(1): 34–43. <https://doi.org/10.1177/1524839916673606>
- Lin, Q., Abbey, C., Zhang, Y., Wang, G., Lu, J., Dill, S.-E., Jiang, Q., Singh, M. K., She, X., Wang, H., Rozelle, S. and Jiang, F. (2022). Association between mental health and executive dysfunction and the moderating effect of urban-rural subpopulation in general adolescents from Shangrao, China: a population-based cross-sectional study. *BMJ Open*, 12(8): e060270. <https://doi.org/10.1136/bmjopen-2021-060270>
- Lindemann-Matthies, P., Benkowitz, D. and Hellinger, F. (2021). Associations between the naturalness of window and interior classroom views, subjective well-being of primary school children and their performance in an attention and concentration test. *Landscape and Urban Planning*, 214: 104146. <https://doi.org/10.1016/j.landurbplan.2021.104146>
- Madzia, J., Ryan, P., Yolton, K., Percy, Z., Newman, N., LeMasters, G. and Brokamp, C. (2019). Residential Greenspace Association with Childhood Behavioral Outcomes. *The Journal of Pediatrics*, 207: 233–240. <https://doi.org/10.1016/j.jpeds.2018.10.061>
- Mavoia, S., Lucassen, M., Denny, S., Utter, J., Clark, T. and Smith, M. (2019). Natural neighbourhood environments and the emotional health of urban New Zealand adolescents. *Landscape and Urban Planning*, 191:103638.

- <https://doi.org/10.1016/j.landurbplan.2019.103638>
- Naya, C. H., Yi, L., Chu, D., Dunton, G. F. and Mason, T. B. (2022). Cross-sectional and longitudinal associations of park coverage, greenness exposure and neighbourhood median household income with children's depressive and anxiety symptoms. *Journal of Paediatrics and Child Health*, 58(4): 662–668. <https://doi.org/10.1111/jpc.15809>
- Nieuwenhuijsen, M. J., Khreis, H., Triguero-Mas, M., Gascon, M. and Dadvand, P. (2017). Fifty Shades of Green: Pathway to Healthy Urban Living. *Epidemiology*, 28(1): 63–71. <https://doi.org/10.1097/EDE.0000000000000549>
- Nishigaki, M., Hanazato, M., Koga, C. and Kondo, K. (2020). What Types of Greenspaces Are Associated with Depression in Urban and Rural Older Adults? A Multilevel Cross-Sectional Study from JAGES. *International Journal of Environmental Research and Public Health*, 17(24): 9276. <https://doi.org/10.3390/ijerph17249276>
- Perrino, T., Lombard, J., Rundek, T., Wang, K., Dong, C., Gutierrez, C. M., Toro, M., Byrne, M. M., Nardi, M. I., Kardys, J., Szapocznik, J. and Brown, S. C. (2019). Neighbourhood greenness and depression among older adults. *The British Journal of Psychiatry*, 215(2): 476–480. <https://doi.org/10.1192/bjp.2019.129>
- Sajady, M., Gower, A. L., McCullough, M. and Jordan, C. (2020). More than a View: School Landscape Features Are Associated with Improved Student Adjustment. *Journal of Developmental and Behavioral Pediatrics*, 41(6): 436–442. <https://doi.org/10.1097/DBP.0000000000000809>
- Shanahan, D. F., Bush, R., Gaston, K. J., Lin, B. B., Dean, J., Barber, E. and Fuller, R. A. (2016). Health Benefits from Nature Experiences Depend on Dose. *Scientific Reports*, 6: 28551. <https://doi.org/10.1038/srep28551>
- Silva, R. A., Rogers, K. and Buckley, T. J. (2018). Advancing Environmental Epidemiology to Assess the Beneficial Influence of the Natural Environment on Human Health and Well-Being. *Environmental Science & Technology*, 52(17): 9545–9555. <https://doi.org/10.1021/acs.est.8b01781>
- Snell, T., Lam, J., Lau, W., Lee, I., Maloney, E., Mulholland, N., Wilson, L. and Wynne, L. (2016). Contact with Nature in Childhood and Adult Depression. *Children, Youth and Environments*, 26: 111–124. <https://doi.org/10.1353/cye.2016.0018>
- Sobko, T., Liang, S., Cheng, W. H. G. and Tun, H. M. (2020). Impact of outdoor nature-related activities on gut microbiota, fecal serotonin, and perceived stress in preschool children: the Play & Grow randomized controlled trial. *Scientific Reports*, 10(1): 21993. <https://doi.org/10.1038/s41598-020-78642-2>
- South, E. C., Hohl, B. C., Kondo, M. C., MacDonald, J. M. and Branas, C. C. (2018). Effect of Greening Vacant Land on Mental Health of Community-Dwelling Adults: A Cluster Randomized Trial. *JAMA Network Open*, 1(3): e180298. <https://doi.org/10.1001/jamanetworkopen.2018.0298>
- South, E. C., Lee, K., Oyekanmi, K., Buckler, D. G., Tiako, M. J. N., Martin, T., Kornfield, S. L. and Srinivas, S. (2021). Nurtured in Nature: a Pilot Randomized Controlled Trial to Increase Time in Greenspace among Urban-Dwelling Postpartum Women. *Journal of Urban Health*, 98(6): 822–831. <https://doi.org/10.1007/s11524-021-00544-z>
- Taylor, L. and Hochuli, D. F. (2017). Defining greenspace: Multiple uses across multiple disciplines. *Landscape and Urban Planning*, 158: 25–38. <https://doi.org/10.1016/j.landurbplan.2016.09.024>
- Vanaken, G.-J. and Danckaerts, M. (2018). Impact of Green Space Exposure on Children's and Adolescents' Mental Health: A Systematic Review. *International Journal of Environmental Research and Public Health*, 15(12): 2668. <https://doi.org/10.3390/ijerph15122668>
- Wang, R., Liu, Y., Xue, D., Yao, Y., Liu, P. and Helbich, M. (2019). Cross-sectional associations between long-term exposure to particulate matter and depression in China: The mediating effects of sunlight, physical activity, and neighborly reciprocity. *Journal of Affective Disorders*, 249: 8–14. <https://doi.org/10.1016/j.jad.2019.02.007>
- Watkins-Martin, K., Bolanis, D., Richard-Devantoy, S., Pennestri, M.-H., Malboeuf-Hurtubise, C., Philippe, F., Guindon, J., Gouin, J.-P., OuelletMorin, I. and Geoffroy, M.-C. (2022). The effects of walking in nature on negative and positive affect in adult psychiatric outpatients with major depressive disorder: A randomized controlled study. *Journal of Affective Disorders*, 318: 291–298. <https://doi.org/10.1016/j.jad.2022.08.121>
- Weeland, J., Lacculle, O. M., Nederhof, E., Overbeek, G. and 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>

- Young, D. R., Hong, B. D., Lo, T., Inzhakova, G., Cohen, D. A. and Sidell, M. A. (2022). The longitudinal associations of physical activity, time spent outdoors in nature and symptoms of depression and anxiety during COVID-19 quarantine and social distancing in the United States. *Preventive Medicine*, 154: 106863. <https://doi.org/10.1016/j.ypmed.2021.106863>
- Zhang, Y., Mavoa, S., Zhao, J., Raphael, D. and Smith, M. (2020). The Association between Green Space and Adolescents' Mental WellBeing: A Systematic Review. *International Journal of Environmental Research and Public Health*, 17(18): 6640. <https://doi/10.3390/ijerph17186640>
- Zhang, Y., Zhao, J., Mavoa, S., Erika, I., Clark, T. C., Crengle, S. and Smith, M. (2022). Urban green space and mental well-being of Aotearoa New Zealand adolescents: A path analysis. *Wellbeing, Space and Society*, 3: 100085. <https://doi.org/10.1016/j.wss.2022.100085>
- Zhang, X., Wei, F., Yu, Z., Guo, F., Wang, J., Jin, M., Shui, L., Lin, H., Tang, M. and Chen, K. (2022a). Association of residential greenness and incident depression: Investigating the mediation and interaction effects of particulate matter. *The Science of the Total Environment*, 811: 152372. <https://doi.org/10.1016/j.scitotenv.2021.152372>
- Zhou, R., Zheng, Y.J., Yun, J.Y. and Wang, H.M. (2022). The Effects of Urban Green Space on Depressive Symptoms of Mid-Aged and Elderly Urban Residents in China: Evidence from the China Health and Retirement Longitudinal Study. *International Journal of Environmental Research and Public Health*, 19(2): 717. <https://doi.org/10.3390/ijerph19020717>