
# The Association Between Natural Features and Momentary Psychological Wellbeing: Do Individual Characteristics Make a Difference?

Submitted by Eva Nielsen, to the University of Exeter

as a thesis for the degree of Doctor of Clinical Psychology, 25th May 2022



I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: ……..

## Author's Declaration

The literature review was completed independently by the author. In terms of the empirical work, participants recruited at time-point two between January 2020 and March 2020 were collected by a Masters student, Laura Nightingale. Her project wrote up different aspects of the measures for the project titled "Exploring the Differential Benefits of Nature on Psychological Well-Being During the COVID-19 Pandemic". A total of 40 participants were tested by Laura Nightingale and 52 by the author.

All other aspects of the study were completed by the author including data entry, analysis, and write up. The study rationale and hypotheses were designed in collaboration with the lead supervisor Professor Celia Morgan. The method was adapted by the author from an existing study and app designed by Bakolis et al. (2018). Analyses were conducted by the author with teaching and supervision from Dr Jennifer Lay, who also assisted with interpretation of the findings.

## Table of Contents

## List of Tables and Figures

**Literature Review**



**Empirical Paper**



.

.

**SCHOOL OF PSYCHOLOGY**

**DOCTORATE IN CLINICAL PSYCHOLOGY**

**LITERATURE REVIEW**

# Associations between nature exposure and psychological wellbeing in adolescents: a systematic review


| | |
|---|---|
| Trainee Name: | **Eva Nielsen** |
| Primary Research Supervisor: | **Professor Celia Morgan**<br>Professor of Psychopharmacology, School of Psychology, University of Exeter |
| Secondary Research Supervisor: | **Dr Nick Moberly**<br>Senior Lecturer, School of Psychology, University of Exeter |
| Target Journal: | PloS ONE |


**Submitted in partial fulfilment of requirements for the Doctorate Degree in Clinical Psychology, University of Exeter**

**Abstract**

***Objective:*** Interventions aimed at promoting wellbeing may be especially important for adolescent populations due to their vulnerability to developing mental illness and the effect this can have into adulthood. Nature exposure has been demonstrated to be positively associated with wellbeing in adults and children, with adolescent research being relatively neglected. Generalising findings from these populations might be unwise due to proposed differences in adolescents' relationship with nature, potentially hindering intervention potential. This systematic literature review aimed to evaluate the evidence for associations between nature exposure and psychological wellbeing in the adolescent population.

***Method:*** Studies investigating the association between nature exposure and hedonic wellbeing in adolescents published prior to 21st October 2021 were selected from PsycINFO (Ovid platform), Medline (Ovid platform), Scopus, and Web of Science databases. They were reviewed using the National Heart, Lung, and Blood Institute (NHLBI) Quality Assessment Tool for Observational Cohort and Cross-sectional Studies (*Study Quality Assessment Tools*, n.d.).

***Results:*** Seven papers were included in the review. These consisted of five cross-sectional studies and two quasi-experimental field experiments varying greatly in sample size, greenspace measures, wellbeing outcomes, and findings. Quality assessment indicated two studies were of poor quality and five were fair.

***Conclusions:*** Heterogeneity within research investigating associations between nature exposure and wellbeing in adolescents was highlighted, making conclusions about such an association difficult at this stage. Higher quality studies were more likely to find less evidence for the association, perhaps indicating a weaker association in line with developmental differences. Further research is necessary if this is to be clarified.

## Introduction

Wellbeing is a multi-faceted measure of positive mental health (Houlden et al., 2018) concerned with realising our best psychological functioning and experience (Ryan & Deci, 2001). It is thought to encompass both hedonic (pleasure and happiness) and eudaimonic (fulfilment and life purpose) factors (Ryan & Deci, 2001), with wellbeing research indicating the highest levels are found in those whose lives contain a combination of both (Huta & Ryan, 2010). Positive psychology has long argued that clinical psychology should be concerned with supporting people to lead fulfilling lives and to realise their potential, not just with treating mental illness (Linley et al., 2006). In light of the actual and potential mental health impact of COVID-19, it has become even more imperative that clinical psychology play a more active role in the development of accessible, preventative public health interventions, as those involving nature exposure are likely to be (Gruber et al., 2021).

Research investigating the association between nature exposure (also referred to as greenspace and/or bluespace where applicable hereafter) and wellbeing has been gaining momentum in recent years across a range of disciplines. A positive association between nature exposure and wellbeing has been evidenced for both children (e.g. Chawla, 2015; McCormick, 2017) and adults (e.g. Bakolis et al., 2018; White et al., 2013), although findings have often been inconsistent (Houlden et al., 2018; Tillmann et al., 2018).

Adolescents, those aged between 10 and 19 years old (World Health Organisation, n.d.), however, have been largely overlooked in this research until very recently. This review aims to systematically assess the current literature investigating the association between nature exposure and wellbeing in adolescents to explore the nature of such an association in this population.

Adolescence is a particularly crucial time for mental health and a time of significant social and emotional changes which may impact wellbeing. Numerous mental health disorders emerge in adolescence (Jones, 2013), as do many health-influencing behaviours (Das et al., 2016). Depression and anxiety typically begin in youth (Werner-Seidler et al.,

2017), with urbanisation being linked to an increase in such emotional disorders amongst adolescents (Rudolph et al., 2014). Identifying potential protective factors against the link between urbanisation and emotional disorders is ever more important as urbanisation increases globally. Harnessing these protective factors for public-health interventions could reduce the burden on future mental health services and promote a healthier population.

Adolescents have been shown to interact with and perceive natural environments differently to adults, potentially using them more for socialising and activity rather than the tranquillity often cited for adults (Huynh et al., 2013). Kaplan and Kaplan (2002) evaluated the findings of several scene-preference studies to demonstrate adolescents' apparent lower preference for natural settings and greater preference for urban scenes denoting activity compared to both older and younger groups. Adolescents were also more likely to cite their homes and more developed places as their favourites (K. M. Korpela, 1992) compared with adults, who were more likely to cite natural settings (K. Korpela, 1991). Kaplan and Kaplan (2002) posited that we have a "time out" from preference for natural environments during adolescence, still showing a liking for these settings but not experiencing the same pull towards them as when younger or older. They suggested this comes at a time of priority shift where peers and the-self become the overriding focuses. This is argued to be key to adolescents' psychological development, enabling integration of the self with others and motivating contribution to society (Crone & Fuligni, 2020).

Studies neglecting adolescents or grouping adolescents with young adults may, therefore, be missing important differences for this population. Life course studies, for example, often integrate older adolescents within their young adult age categories. Although their findings may be indicative of adolescent reactions, age differences may exist within the category, which would not be accounted for but may skew the findings. It is thus unclear who these findings are applicable for and whether they would truly represent adolescents. In a study on freshwater blue spaces, for example, de Bell et al. (2017) found young adults aged 16-24 were half as likely as 45-64 year olds and a third as likely as those over 65 years old

to find nature important. This is potentially important for the adolescent nature exposure-wellbeing association, but is it more attributable to the adolescents or the young adults in the category?

Some research has been conducted investigating the association between greenspace and other areas of health for adolescent populations, with differing results. Astell-Burt et al., (2014), for example, compared greenspace-mental health associations across adulthood including an older-adolescent age group. They found greenspace exposure to have little association with young men's mental health at 15-20 years old compared with mental health improvements evident with increased green space in those aged 30-81 years. Women aged 15-20 years exposed to moderate levels of neighbourhood greenspace were found to have lower levels of mental health compared to those with low greenspace exposure. Woodland exposure was associated with improved cognitive development and reduced risk of behavioural and emotional difficulties for young adolescents aged 9-15 years in a study by Maes et al. (2021), with no such result for grassland or blue-space exposure. Li et al. (2018) found positive associations between nature exposure and mood for 13- to 19-year-olds, whereby increases in greenness were associated with decreases in mood disturbance. No associations between high school greenspace and levels of mental and physical health were found by Akpinar (2016) for 12-20 year old participants, which is in contrast to the findings of child-focussed literature (Chawla, 2015). Inconsistency in findings for adolescents in relation to greenspace associations highlights the need for systematic review to enable evaluation of the evidence more broadly.

The construct of wellbeing has been an area of contention within psychological research over many years. Two forms of wellbeing have emerged as aspects of the same multi-dimensional concept: hedonic and eudaimonic wellbeing (Ryan & Deci, 2001). Hedonic wellbeing concerns pleasure and happiness, whilst eudaimonic wellbeing is concerned with fulfilment and life purpose (Ryan & Deci, 2001). Although initially treated as distinct (Stavraki et al., 2022), it has more recently been established that the two facets influence and build on

one another (Pritchard et al., 2020). It has been shown, for example that the positive emotions integral to hedonic wellbeing help to build personal resources, which in turn build a person's future eudaimonic wellbeing (Fredrickson, 2004).

In terms of adolescents, the measurement of different aspects of wellbeing is less well established. Where specific measures have been developed, they have tended to focus on hedonic, rather than eudaimonic wellbeing (Stavraki et al., 2022). It is possible that some aspects of eudaimonic wellbeing cannot be assessed in the same way for adolescents as their adult counterparts. This is due to developmental differences, such as the finding that younger adolescents are less future orientated than older adolescents (and adults) (Steinberg et al., 2009). This has a likely influence on eudaimonic aspects such as 'purpose in life' and 'personal growth' (Ryff, 1989). It may be problematic, therefore, to apply eudaimonic measures designed for adults to adolescent participants without further clarification of their suitability, as the validity of findings may be compromised. As such, for the purpose of the current literature review, it was decided to include measures of hedonic wellbeing, rather than eudaimonic.

In summary, recommendations and interventions aimed at increasing wellbeing may be especially important for adolescents at a vulnerable time for development of mental illness. Nature exposure may be one way to achieve this, as has been shown for children and adults. As differences have been found in adolescents' reactions to nature, however, the generalising of findings from other age groups may lead to inaccurate assumptions and overgeneralisations hindering intervention efficacy. The current review, therefore, aims to evaluate the evidence for associations between nature exposure and psychological (hedonic) wellbeing in the adolescent population.

## Method

The systematic review was conducted following the Preferred Reporting Items for Systematic review and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). See

Appendix C for PRISMA checklist. A protocol was not submitted prior to this review being conducted.

**Eligibility Criteria**

Studies were included if they included a focus on the potential association between nature exposure and wellbeing in an adolescent population. Searches were limited to articles published before 21st October 2021, as this was when the search was conducted. No early time limit was stipulated to allow for a broad search, especially as the field is relatively new. Further exclusion and inclusion criteria were based on a Population, Exposure, Comparator, Outcomes (PECO) framework, without Comparator due to typical lack of control groups in the literature and are detailed in Table 1. Exposure to nature could include incidental exposure within daily life, e.g. neighbourhood greenspace, or experimental exposure to natural elements/environments, but not in the context of nature-based activities or wilderness programmes. This was due to the potential confounding variables of such programmes, including social aspects, the activities themselves, being away from home for extended periods etc.

The outcomes included were those where a measure of positive aspects of hedonic wellbeing was included. Search terms were thus related to outcomes based on positive affect and life satisfaction (Pritchard et al., 2020). Negative affect was not included in line with Houlden et al.'s (2018) definition of wellbeing as a measure of positive mental health over and above absence of mental distress. Studies were excluded if using quality of life as a proxy for wellbeing as this typically includes additional focus on objective indicators not included in measures of subjective wellbeing (Theofilou, 2013).

**Table 1**

*Study Inclusion and Exclusion Criteria*

| Inclusion | Exclusion |
|---|---|
| **Population** | **Population** |

| | |
|---|---|
| • Whole or distinct group of sample aged between 10 and 19 years-old.<br>• Clinical or non-clinical populations. | • Studies where participant age range could not be determined.<br>• Participant group with learning disabilities.<br>• Participant group with chronic physical health difficulties. |
| **Exposure**<br>• Neighbourhood vegetation/greenspace.<br>• Exposure to nature as part of study design.<br>• Exposure to greenspace/nature within daily life.<br>• Greenspace and/or bluespace, or a mixture. | **Exposure**<br>• Focus on virtual nature exposure.<br>• Nature exposure accessed via an activity/wilderness programme.<br>• Forest school programmes. |
| **Outcomes**<br>• Include a measure of hedonic wellbeing.<br>• Focus on positive hedonic aspects of wellbeing including positive affect, life satisfaction, happiness. | **Outcomes**<br>• Quality of Life measure used as proxy for wellbeing.<br>• Only measures focusing on negative symptoms, e.g. symptoms of mental illness, negative affect etc.<br>• Studies with only eudaimonic wellbeing measures. |
| **Study Design**<br>• Quantitative studies including (but not limited to): cross-sectional, experimental, cohort, field experiments, survey designs. | **Study Design**<br>• Qualitative studies.<br>• Case-studies. |
| **Additional Limits**<br>• Published before 21st October 2021.<br>• English language.<br>• Peer-reviewed | |

### Information Sources and Search Strategy

Relevant studies were identified using electronic searches of the following databases: PsycINFO (Ovid platform), Medline (Ovid platform), Scopus, and Web of Science. Search terms were generated using relevant terms from previous systematic reviews (Gascon et al., 2015; Oswald et al., 2020). Following the PECO framework, terms

were divided into three themes, which were nature exposure, adolescence, and psychological wellbeing. Terms within each theme were divided by the Boolean operator "OR" and themes were combined using the Boolean operator "AND". Keywords for each theme adapted for Ovid databases can be found in table 2, with search strategies for other databases in Appendix A. Search strings were adapted to meet the criteria of each database to ensure detection. Subject headings were used in Ovid where relevant (see table 2) but were not appropriate in other databases. Terms were searched for within the title and abstract fields to ensure relevance to the research question. Databases were searched for relevant literature published before 21st October 2021.

**Table 2**

*Search Terms for Ovid Databases*

| PECO criteria | Theme | Search terms | Subject Heading |
|---|---|---|---|
| **Population** | Adolescence | ((teen*) or (adolescen*) or (youth*) or (juvenile*) or (young people) or (young person) or (young adult*) or (lifecourse) or (life course) or (lifespan) or (life span)) | |
| **Exposure** | Nature exposure | ((green?space) or (green adj2 space*) or (green space*) or (greenspace*) or (greenness) or (greenery) or (green belt*) or (green corridor*) or (natural environment*) or (open space*) or (park) or (parks) or (natur* space*) or (naturalness) or (garden*) or (canopy) or (tree*) or (forest*) or (woodland*) or (urban nature) or (biodiversity) or (outdoor*) or (blue space*) or (blue?space) or (coast*) or (sea) or (tree) or (water) or (river) or (lake) or (beach) or (ocean) or (marine)) | OR NATURE (ENVIRONMENT) |
| **Outcome** | Psychological Wellbeing | ((wellbeing or well-being or well being or wellness or positive affect or restoration or positive emotion* or (increased adj2 mood) or (heightened adj2 mood) or (improved adj2 | OR WELL BEING |

| | |
|---|---|
| | mood) or happiness or pleasure or (life adj5 satisfaction)) |

**Evaluation Criteria**

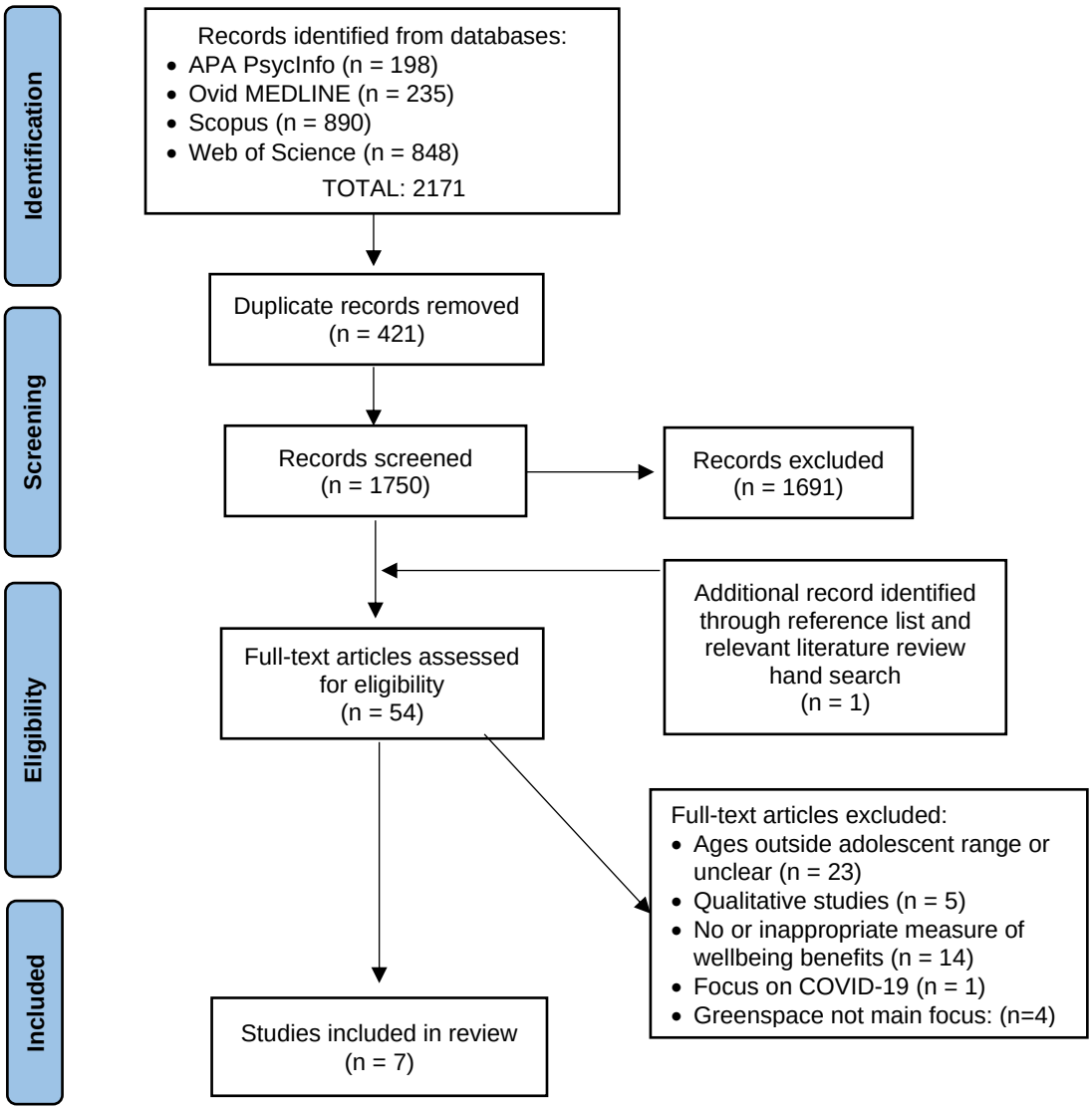
Included studies were evaluated using the National Heart, Lung, and Blood Institute (NHLBI) Quality Assessment Tool for Observational Cohort and Cross-sectional Studies (*Study Quality Assessment Tools*, n.d.). This tool provides a series of 14 questions to stimulate study quality appraisal according to structured criteria. Items relate to study sample, exposure and outcome measures, and attention to confounding variables. The tool requires Yes, No, or Other (cannot determine, not applicable, or not reported) answers for each item. The items encourage general evaluation of the risk of bias within each reported study and are used to inform an overall quality rating of Good, Fair, or Poor. Guidance is included with the assessment tool (Appendix B). The tool was chosen due to the prevalence of cross-sectional studies within nature-wellbeing literature and its attention to studies investigating exposures and outcomes relating to health (Li et al., 2021). Three of the papers were independently assessed by a second reviewer with good agreement (kappa = .89). Six papers were also assessed to check agreement for inclusion within the review with complete agreement found.

## Results

A total of 2171 articles were retrieved from the four databases included. Following initial screening and assessment of eligibility, as seen in figure 1, seven articles remained for inclusion in the review.

**Figure 1**

*PRISMA Flowchart.*




**Study Characteristics**

Summaries of the included articles can be seen in Table 3. Included studies were conducted in Iran, Canada, and Austria (n=1), and New Zealand and the United Kingdom (n = 2 in each location). Sample sizes ranged from 60 to 17,249 adolescents aged between 10 and 19 years old. Most studies were cross-sectional (n = 5), with four using existing large-scale survey data. The remaining two studies were quasi-experimental field experiments.

**Table 3**

*Article Summaries and Key Findings for Included Studies.*

| Reference | Objective | Sample | Method/ Design | Nature Exposure of Interest | Wellbeing Outcomes | Wellbeing Findings |
|---|---|---|---|---|---|---|
| Dadvand et al. (2019) | Evaluation of the association between time spent in greenspace of different types and adolescents' self-satisfaction and social interaction. | 10 856 participants. 10-18 year-olds in Iran. 48.1% female. | Cross-sectional survey - Childhood and Adolescence Surveillance and Prevention of Adult Non-communicable disease study (CASPIAN-V). | Time spent in greenspace (divided into parks, forests, gardens) | Self-satisfaction | Higher greenspace time associated with improved self-satisfaction and social contacts. Self-satisfaction association was stronger for adolescents aged 14+. Social contacts associations were stronger for boys, older adolescents, rural dwelling participants, and for the lowest and highest SES groups. Social contacts explained 59.9% of greenspace-self-satisfaction association. |
| Greenwood and Gaterslebe n (2016) | Investigation of whether natural environments are restorative for adolescents and the role of 'doing something' and social context when in nature. | 120 participants. Aged 16-18 years old. 55% female. UK. | Field experiment | Different restoration conditions – inside/outside with natural elements and alone/with friend/with phone. After exposure to stressful cognitive tasks. | Affect: Zuckerman's Inventory of Personal Reaction (1977) – measures of positive affect and attentiveness included. | Positive affect improved more after time spent outdoors than indoors.<br>Greater increases in positive affect seen when with a friend compared to alone or with mobile phone. No difference in concentration levels whether alone or with a friend outdoors, but significant difference in positive affect, with an increase if with a friend compared to decreases if alone. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Huynh et al. (2013) | Examination of the relationship between public natural space and positive emotional well-being for adolescents. | 17 249 students in 317 schools in Canada. Grades 6-10 (mostly aged 11-16). 51.6% female. Excluded those travelling more than 1 hour to school, those with missing data for key variables. | Cross-sectional survey – 2009/10 Health Behaviour in School-aged Children (HBSC) Survey. | Used CanMap Route Logistics (version 2009.4) and Enhanced Points of Interests (version 2009.3) databases to obtain public natural environment feature data. Linked to school addresses with 5km buffer as neighbourhood environment proxy. Public natural space included total natural space, blue- and green-space. | Positive emotional well-being using Cantril Ladder (Cantril, 1965). | Public natural space was not strongly associated with positive emotional wellbeing for adolescents. Associations were weak and inconsistent. Small positive association between well-being and natural space in small cities. Moderate exposure to natural space suggested to be most beneficial. |
| Mavoa et al. (2019) | Assessing relationship between residential natural environment and urban-dwelling adolescents' mental and emotional health in New Zealand. | 4757 participants. New Zealand secondary school students years 9-13 – approximately aged 12-19 years. 56.6% female. Excluded rural dwellers, those reporting more than one home, those with missing data. | Cross-sectional survey – 2012 Youth2000 Survey. | Natural environment in residential neighbourhood, including average greenness (NDVI), biodiversity, bluespaces, composite nature index. | Emotional wellbeing – World Health Organisation-5 Well-being Index (WHO-5). | Only natural environment measure associated with wellbeing was standard deviation of greenness. Significant negative relationship found between greenness variability and wellbeing, with lower wellbeing associated with increased variability in 800m and 1600m neighbourhoods.<br><br>Blue space measures not significantly associated with emotional health. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mueller & Flouri (2021) | Investigation of link between neighbourhood greenspace and self-esteem, positive and negative mood, happiness, and anti-social behaviour in UK adolescents. Exploration of whether perceived area safety, garden access, and physical activity play a role in this association. | 4534 11-year-old urban adolescents in UK. 49.7% female. Only those who lived in urban areas and had never moved address included. Rural-dwelling participants excluded. | Cross-sectional – UK Millenium Cohort Study (MCS) – sweep 5 (January 2012 – February 2013). | Neighbourhood greenspace – data from Multiple Environmental Deprivation Index (MEDIx).<br>Neighbourhood air pollution – data from MEDIx.<br>Neighbourhood deprivation – data from sweep 1 of MCS.<br>Perceived area safety – "How safe is it to walk, play, or hang out in this area during the day?".<br>Availability of parks or playgrounds – "Are there any parks or playgrounds in this area where children your age can play?" | Self-esteem – 5 items of Rosenberg self-esteem scale.<br>Happiness – 6 items asking about feelings regarding different life aspects (taken from previous studies).<br>Positive and negative mood – 6 items on experience of positive and negative feelings | No association between greenspace and outcomes. Four interaction effects were found: garden access modified greenspace-self-esteem and positive mood associations, whereby for those without gardens, higher neighbourhood greenspace associated with lower levels of self-esteem and positive mood; Physical activity moderated greenspace-negative mood effect, whereby for those reporting less physical activity, higher neighbourhood greenspace associated with lower levels of negative mood; |
| Wallner et al. (2018) | Investigation of effect on adolescents' wellbeing and cognitive performance of spending lunchbreak in | 60 16-18 year-old pupils from 3 schools in Vienna participated as school classes. 50% female. | Cross-over field experiment. 3 conditions completed at least 7 days apart. | 3 different settings: small inner urban heavily used park with a few trees, larger park with some tree clumps; larger broadleaf forest with meadows and low | Wellbeing – Self-condition scale to assess momentary mood state administered 4 times throughout each condition. | Either significant improvement or trend to improve wellbeing found after time in greenspaces. Cannot say whether this is due to the break, travel to break location, or location of the break.<br>Wellbeing scores comparable for all sites for earlier measurements. Sustained |

| | | | | | | |
|---|---|---|---|---|---|---|
| | different urban greenspace. | | | use. Stayed for 1 hour lunchbreak. | | effects for some wellbeing variables found only for forest area condition. |
| Ward et al. (2016) | Investigating the relationship between time spent in greenspace and physical and psychological variables for children. | 108 11-14 year-olds from intermediate schools, New Zealand. Only 72 with full GPS data. 56.94% of these were female. | Cross-sectional observational study. | GPS data from worn belt mapped against Open Street Map data on parks, reserves, and sports fields open to public. | Emotional wellbeing – Life Satisfaction Scale from Hebener's Student Life Satisfaction Scale; Ten Domain Index of Wellbeing; Single item happiness with life as a whole measure. | Stronger relationship between level of greenspace exposure and emotional wellbeing than with physical activity. Every added 1% of greenspace time associated with 0.66 increase in life satisfaction score compared with 0.18 increase with 1% increase in moderate-vigorous physical activity. Happiness and Ten Domain Index of Wellbeing significantly related to greenspace but not physical activity. |

**Table 4**

*Results of NHBLI Quality Assessment Tool.*

| Study | NHBLI Quality Assessment Tool Item | | | | | | | | | | | | | | Overall Rating |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | |
| **Dadvand et al. (2019)** | Y | Y | Y | Y | N | NA | NA | Y | N | N | N | NA | NA | Y | **Poor** |
| **Greenwood and Gatersleben (2016)** | Y | N | CD | CD | Y | Y | Y | N | Y | N | Y | N | NA | N | **Fair** |
| **Huynh et al. (2013)** | Y | Y | Y | Y | Y | N | NA | Y | Y | N | Y | NA | NA | Y | **Fair** |
| **Mavoa et al. (2019)** | Y | Y | Y | Y | N | N | NA | Y | Y | N | Y | NA | NA | Y | **Fair** |
| **Mueller & Flouri (2021)** | Y | Y | N | Y | N | N | NA | Y | Y | NA | Y | NA | NA | Y | **Fair** |
| **Wallner et al. (2018)** | Y | Y | CD | N | N | Y | Y | Y | N | Y | Y | CD | NA | N | **Poor** |
| **(Ward et al., 2016)** | Y | Y | N | Y | Y | N | NA | N | N | Y | Y | NA | NA | N | **Fair** |

Y = Yes, N = No, NA = Not Applicable, CD = Cannot Determine.

**Key:** 1. Was the research question or objective in this paper clearly stated?
2. Was the study population clearly specified and defined?
3. Was the participation rate of eligible persons at least 50%?
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?
5. Was a sample size justification, power description, or variance and effect estimates provided?
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
10. Was the exposure(s) assessed more than once over time?
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
12. Were the outcome assessors blinded to the exposure status of participants?
13. Was loss to follow-up after baseline 20% or less?
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?

**Risk of Bias**

Table 4 summarizes the results of study appraisal using the NHBLI Quality Assessment Tool. Overall, the quality of five studies was rated ‘Fair’, with two rated ‘Poor’. It should be noted that these ratings are not based on an objective tallying of items but rather an overall evaluation of quality, informed by the tool items. The items were broadly grouped into five categories of interest to synthesise the results. These are presented below alongside the study findings in relation to the review question.

**Study Aims**

The five cross-sectional studies all had general aims around the association between different levels of greenspace in participants’ environments and levels of wellbeing. The two quasi-experimental studies had more specific aims including whether lunch in different urban greenspaces influenced wellbeing, and whether an environment with natural elements had a restorative effect following stress-inducing tasks and whether this was influenced by social interaction or playing on a phone in that environment. All objectives were clearly defined (see table 3).

**Study Samples**

The study populations were clearly defined in six out of seven studies and are summarised in Table 3. A total of 37,657 participants aged between 10- and 19-years-old were included across all seven studies. Dadvand et al. (2019) included the broadest age range, with participants aged between 10 and 18 years old. Huynh et al. (2013) had the largest sample with 17,249 participants. All studies were relatively balanced in relation to gender, with percentage of female participants ranging from 48.1% to 56.94%. The majority of studies included urban-dwelling adolescents only, either through city locations (Greenwood & Gatersleben, 2016; Wallner et al., 2018) or by explicitly excluding rural

dwellers (Mavoa et al., 2019; Mueller & Flouri, 2021). Only one study included reference to rural dwellers within their analysis and results (Dadvand et al., 2019).

Greenwood and Gatersleben (2016) gave some details regarding participant age range and gender, school location, and months of assessment, but did not clarify other potentially important demographic information, such as SES or ethnicity, especially relevant given likely heterogeneity due to the study's London location, or state which year the study was undertaken. They did not provide inclusion/exclusion criteria, nor state how many eligible persons did not participate.

No study included a sample size justification, although Ward et al. (2016) cited potential lack of statistical power due to sample size as a possible explanation for undiscovered associations. Effect sizes were referenced in two studies (Greenwood & Gatersleben, 2016; Huynh et al., 2013). Each of the studies using existing survey data included large sample sizes ranging from 4534 to 17,249 participants, while the experimental designs ranged from 60 to 120 participants. Although use of a within-participant design for the smallest of these (Wallner et al., 2018) will have increased its power (Lakens, 2022). It is possible that sample size calculations were performed but not reported. However, as informative studies are said to require sample size justification (Lakens, 2022), it is considered a flaw not to provide details of this within the study's report.

Studies took place in a range of different countries including Iran (Dadvand et al., 2019), UK (Greenwood & Gatersleben, 2016; Mueller & Flouri, 2021), New Zealand (Mavoa et al., 2019; Ward et al., 2016), Austria (Wallner et al., 2018), and Canada (Huynh et al., 2013). As is often the case in research within the field (Zhang et al., 2020), the majority of these are developed countries.

**Natural Exposure Measure**

Varied measures of nature exposure were utilised, as can be seen in table 3. Several objective measures were used, including percentage of public natural green- and blue-space

in 5km buffers around participant's schools (Huynh et al., 2013), residential neighbourhood greenspace using normalised difference vegetation index (NDVI) (Mavoa et al., 2019) and the Multiple Environmental Deprivation Index (MEDIx) (Mueller & Flouri, 2021), and GPS data mapped against Open Street Map (www.openstreetmap.org) data for public parks, sports fields, and reserves (Ward et al., 2016). Only two studies included measures of bluespace (Huynh et al., 2013; Mavoa et al., 2019).

Wallner et al. (2018) included brief subjective description of the tree coverage in the different urban parks used, however, with no apparent objective measurement of this. Greenwood & Gatersleben (2016) did not include differing levels of greenspace within their study, instead comparing an outside area with "natural elements" to an inside, windowless room. Dadvand et al. (2019) was the only study to rely on self-reported greenspace exposure, asking participants to retrospectively report their average weekly greenspace time, divided into three types of green space, on weekdays and weekends for each season over the previous 12 months, a measure likely to have been subject to recall bias.

Lack of objective measurement of the greenspaces utilised in Wallner et al.'s (2018) and Greenwood and Gatersleben's (2016) studies, nor participant reported perception of greenspace, makes conclusions regarding greenspace exposure problematic. It would be difficult to attribute greenspace associations with wellbeing to the greenspace when the composition or perception of this is not known. Lack of inclusion of varying amounts of greenspace for Greenwood and Gatersleben (2016) make it impossible to attribute findings to the natural elements cited in the outside condition, rather than, for example, a negative association between elements of the inside room condition and wellbeing, as was noted by the authors themselves. The brief description of park differences by Wallner et al. (2018, see table 3) indicated attention to differing levels of greenspace but without sufficient detail or measurement to allow replication or determination of what any differences might be attributable to. This also reduces the usefulness of these findings in terms of informing recommendations or intervention.

Limitations are also noted for the more objective measures. The MEDIx, for example does not measure greenspace smaller than 5 $m^2$, does not include domestic gardens and does not account for greenspace accessibility (Mueller & Flouri, 2021). Ward et al. (2016) were also limited to public greenspace areas, without account of domestic greenspace. These limitations could have important implications regarding participants' actual exposure to and use of greenspace that would not be accounted for.

Although it is important to capture incidental nature exposure well, restricting natural environment evaluation to neighbourhood and school neighbourhood greenspace may not capture all intentional exposure, as participants may travel outside of these areas to access this. This type of exposure may represent more concentrated, higher quality natural environments, potentially having an important effect on wellbeing.

**Wellbeing Measure**

Heterogeneity could also be seen in the breadth of wellbeing measures employed, with no studies utilising the same measure (see table 3 for details). Wellbeing was measured by assessing life satisfaction (Huynh et al., 2013; Ward et al., 2016), self-satisfaction (Dadvand et al., 2019), positive affect (Greenwood & Gatersleben, 2016), self-esteem, happiness, and mood (Mueller & Flouri, 2021), and momentary mood state (Wallner et al., 2018), as well as more general measures of wellbeing (Mavoa et al., 2019; Ward et al., 2016). Six studies used, at least some, standardized measures, while Dadvand et al. (2019) used a single item apparently idiosyncratic measure of self-satisfaction ("How satisfied are you with yourself?"). Although not all of Mueller and Flouri's (2021) measures were standardised, they were explicit about this, stating where they had been previously used or including principle components analysis to increase interpretability (Jollife & Cadima, 2016) of new measures.

Consistent with a previous literature review assessing greenspace-wellbeing associations in adults (Houlden et al., 2018), most studies assessed only elements of

wellbeing. Mueller and Flouri (2021) and Ward et al., (2016) used combinations of different measures to assess different aspects of hedonic wellbeing.

**Confounding Variables**

An area of weakness for three of the studies (Greenwood & Gatersleben, 2016; Wallner et al., 2018; Ward et al., 2016) was the overlooking of known confounding variables. In contrast, the larger survey studies (Dadvand et al., 2019; Huynh et al., 2013; Mavoa et al., 2019; Mueller & Flouri, 2021) each accounted for a variety of variables, such as SES, gender, ethnicity, and urbanity of residential location, within their analyses. As such factors have been shown to influence the greenspace-wellbeing association (e.g. Li et al., 2021), their omission may have important implications for generalisability of the findings. Additionally, as the impact of these factors remains unclear in the research (Zhang et al., 2020), consistent inclusion within relevant studies could help to clarify their influence on the greenspace-wellbeing association.

Two of the experimental studies noted potential difficulty determining attribution of findings to the exposure of interest as opposed to other confounds. As noted by the authors, they were unable to attribute wellbeing variation to greenspace rather than, for example, travel to the break locations (Wallner et al., 2018) or negative impact of the alternative windowless room condition (Greenwood & Gatersleben, 2016).

**Findings**

Four studies found positive associations between nature exposure and wellbeing for adolescents (Dadvand et al., 2019; Greenwood & Gatersleben, 2016; Wallner et al., 2018; Ward et al., 2016). Increased time spent in greenspace was associated with improved self-satisfaction, which was stronger for adolescents older than 14 years than those in aged 10-13 years (Dadvand et al., 2019), positive affect (Greenwood & Gatersleben, 2016), and happiness, general wellbeing, and life-satisfaction (Ward et al., 2016). In Wallner et al.'s

study (2018) a break spent in various urban greenspaces was also associated with improving wellbeing, although this may have been attributable to other factors (see above). The latter author did, however, also find sustained wellbeing effects for the forest condition only, indicating a possible greenspace-specific effect.

Although these studies found positive nature exposure-wellbeing associations, several methodological issues would suggest approaching these findings with some caution. The nature exposure measures used were either open to bias (Dadvand et al., 2019) or did not allow for comparison of different levels/types of nature (Greenwood & Gatersleben, 2016; Wallner et al., 2018; Ward et al., 2016). Several also did not sufficiently control for potential confounding variables (Greenwood & Gatersleben, 2016; Wallner et al., 2018; Ward et al., 2016). These factors make conclusions about nature's association with wellbeing difficult to clarify and would warrant further study to allow this.

No or inconsistent weak associations were found in two studies, with Mueller and Flouri (2021) finding no main effect of greenspace with any of their outcomes and Huynh et al. (2013) concluding that public natural space was not strongly associated with wellbeing. An exception to this latter finding was shown for small cities, where a small positive association was found. No evidence was found for an association between bluespace and wellbeing in the two studies including measures and analysis of this (Huynh et al., 2013; Mavoa et al., 2019).

Some negative associations were also found, with greenness variability being associated with reduced wellbeing (Mavoa et al., 2019), and an interaction effect whereby those without gardens showed an association between higher neighbourhood greenspace and lower levels of self-esteem and positive mood (Mueller & Flouri, 2021). See table 3 for further details.

Methodologically, the three studies finding no, weak, or negative associations were stronger than those finding positive associations. Although each had some issues in terms of

reporting, they each better controlled for confounding variables, used more comprehensive measures of nature exposure, and included large sample sizes.

## Discussion

The aim of this review was to explore the association between nature exposure and wellbeing in adolescents evident in current literature. Although positive associations were cited for four of the seven included studies, two of these were assigned ‘Poor’ ratings during quality appraisal, indicating their findings may not be reliable. With the exception of Dadvand et al. (2019), which was one of the ‘Poor’ rated studies, the studies citing positive associations were conducted with the smallest sample sizes, between 60 and 120 participants. This again raises potential concerns around reliability and generalisability. The remaining three studies found no, weak, or negative associations. The strength of association between nature exposure and wellbeing in adolescents therefore remains unclear, with inconsistent findings and methodological issues making conclusions difficult to attribute to a nature exposure-wellbeing association rather than other study aspects.

Several limitations of the different nature exposure measures utilised by the studies were noted, with several appearing open to bias. The retrospective nature of Dadvand et al.'s (2019) retrospective measure, for example, relied on participants accurately remembering 52 weeks of greenspace access according to both season and greenspace type. The inaccuracy of retrospective self-report measures has been well studied, with Bernard et al. (1984) concluding that half of retrospective self-reports in the literature they reviewed were likely to be inaccurate. Frequency recall tends to be based on inference and partial recall, except in cases where the behaviour is particularly rare and important (Schwarz, 2007). Weekly time spent in neighbourhood greenspace is unlikely to meet these criteria and is therefore likely subject to inaccurate recall. Numerous reasons have been cited to account for the particular susceptibility of children to these recall inaccuracies (Cale, 1994), such as level of cognitive development and difficulties estimating time, although it is

suggested these are less problematic for those over 10 years old (Sallis, 1991), as was the case for Dadvand et al. (2019).

The most common measures were objective using land-use databases and satellite imagery. It was noted that two of these (Mueller & Flouri, 2021; Ward et al., 2016) did not include measures of domestic greenspace, such as gardens, and that the MEDIx used by Mueller and Flouri (2021) did not include small areas of greenspace. Previous research has illustrated the importance of even elements of nature (e.g. Bakolis et al., 2018) for the wellbeing of adults, and gardens were even shown by Mueller and Flouri (2021) to impact wellbeing, with those reporting they did not have one showing a negative association between neighbourhood greenspace and self-esteem. The omission of these areas from some studies thus has an impact on the validity of their findings.

The use of objective measures in all but one study also prevents any inferences in terms of participant's perception of nature or their connection to it. This may be especially important for the adolescent population due to their possible differences in preference for these areas (R. Kaplan & Kaplan, 2002). Nature connection has been shown to be an important component in the link between nature and positive benefits. Friedman et al. (2022), for example, cited an increase in children's connection to nature during COVID-19 restrictions as associated with lower levels of emotional and behavioural difficulties compared to those with stable or reduced connection. Mayer et al. (2009) used mediational analyses to demonstrate that nature connectedness partially mediated the association between nature exposure and increased positive emotion found across their three studies. Nature connection may, therefore, play an important role in the nature exposure-wellbeing association.

A combination of subjective self-reported measures alongside the objective exposure measures may therefore be necessary to gain a clearer picture of how and for whom the association is occurring. It is recognised, however, that this comprehensive assessment of greenspace exposure is difficult and would require significant resources and multiple

different measures to achieve. The heterogeneity of exposure measures used is a theme shared by previous literature reviews (Britton et al., 2018; Gascon et al., 2015; Houlden et al., 2018; Oswald et al., 2020; Zhang et al., 2020) and highlights the continuing lack of consensus around these.

Assessment of wellbeing was also heterogenous, which is again in line with adult literature reviews (e.g. Houlden et al., 2018). Failing to measure the variety of aspects contributing to hedonic wellbeing may mean studies miss important associations, drawing inaccurate conclusions as a result. Agreement over outcome measures would allow for more fruitful comparison across studies.

The unclear findings for adolescents may reflect a potentially more unclear connection to nature. A commonly cited theory explaining people's affinity for nature is Attention Restoration Theory (S. Kaplan, 1995), which suggests natural environments are especially successful at restoring attentional resources following mental fatigue. People are thought to be inherently fascinated by natural environments, attending to them effortlessly (A. E. van den Berg et al., 2010). When this apparently effortless attention occurs, directed attention systems are able to recover and restore (S. Kaplan, 1995). It may be that due to adolescents' developmental focus on the-self and others (R. Kaplan & Kaplan, 2002), they are not as likely to attend to and be fascinated by the nature around them, thus missing out on some of its restorative benefits.

In terms of clinical interventions aimed at harnessing nature's association with wellbeing for adolescents, it appears possible that passive exposure to nature may not be sufficient for this population. Nature based activities including other, more developmentally salient components, such as social interaction and opportunity to learn new skills and display competence might have more benefits at this stage (R. Kaplan & Kaplan, 2002). Building confidence and feelings of accomplishment and competence were frequently cited benefits of the nature activity studies for adolescents included in Roberts et al.'s (2020)

systematic literature review. These may therefore be more beneficial areas of wellbeing to focus on for adolescent interventions.

**Limitations**

Several limitations of the current review should be noted. Inclusion of only seven studies means findings cannot easily be generalised to adolescents more broadly and may have limited the likelihood of finding consistent results. Expansion of the inclusion criteria to encompass older young people or those studies with some participants outside the age range may have helped with this, although this then creates difficulties if adolescents do, in fact, respond differently to young adults. There has been a general dearth of studies focussing specifically on adolescents, which, as illustrated by the recency of the included studies, appears to be reducing. A repeated literature review in the near future may, therefore, discover a broader range of studies.

Exclusion of non-English language papers likely limited the pool of studies further and may have played a part in the under-representation of studies from developing countries. This poses difficulties in terms of generalisability, as it cannot be determined whether any associations found would remain relevant for those in developing countries or countries where English is less widely spoken. As this is a common exclusion criteria in previous relevant literature reviews (e.g. Gascon et al., 2015; Houlden et al., 2018; Zhang et al., 2020), concentration on non-English language studies for a future review may be especially useful to inform the broader global picture. Execution of this would likely require collaboration across many researchers to ensure accuracy and consistency of data extraction for each language.

Inclusion of only peer-reviewed articles is another potential limitation of the search criteria. Publication bias may have meant that articles finding no or weak associations were less likely to be accepted for peer-reviewed journals and may, therefore have been missed from the current review. A further extension would be to include grey literature in the search to see if this would expand the number of studies found.

A limitation of the NHLBI Quality Assessment Tool was the relatively subjective nature of the overall quality rating. Lack of objective means of item calculation, although allowing for nuance in the evaluation of different items and the study as a whole, also allows for increased rating bias in that different individuals may place more weight or value on different tool items.

**Future Research**

To clarify the potential differences between adolescents and older and younger populations, future studies could include direct comparisons of different age groups within the same study. It would be important to ensure adolescents are grouped separately to young adults if the “time out” from nature theory (R. Kaplan & Kaplan, 2002) is correct. To further assess this, it may also be useful to compare active and passive greenspace exposures, as Greenwood and Gatersleben (2016) began doing, to assess whether greenspace benefits may be more dependent on activity for adolescents, as has been suggested by Huynh et al. (2013) and Kaplan and Kaplan (2002). This would be important for recommendation and intervention design to ensure maximum benefits are reaped.

Agreement over outcome and wellbeing measures would allow for direct comparison of different groups under different circumstances to allow investigation of what works best for whom. Future replication and extension of the highest quality studies may be a way to achieve this. Cross-disciplinary collaboration may be another way to reach a consensus, as the existing studies hail from a range of different fields, with likely differences in research conventions and standards.

The common use of cross-sectional designs within this review and the literature in general prevents inferences regarding causation of any associations found. This is limiting in terms of the creation of interventions, as clinicians would not yet be able to say that nature exposure causes an increase in wellbeing and should thus be recommended. Findings remain open to the possibility that those with higher wellbeing seek out more natural

environments or are better able to connect with them. Further experimental, longitudinal research is therefore warranted to clarify causation and therefore inform intervention.

## Conclusion

This systematic review highlighted the heterogeneity within nature exposure-wellbeing research with adolescents. The potential for a positive association between nature exposure and wellbeing for adolescents was evident in some studies but these tended to be those with more methodological concerns. Other, potentially higher quality, studies found minimal evidence for a positive association or even a negative association. This and issues of study quality in general mean that, overall, the evidence is not adequate enough to draw conclusions regarding the association between passive nature exposure and wellbeing for adolescents at this time. Those aiming interventions at this population should therefore be wary, as the evidence-base remains unclear and would not currently justify their use. Research in the field continues to increase, however, so it is hoped this picture will be clarified in the near future. This is especially important if the findings can be used to inform public-health level preventative interventions.

## References

Akpinar, A. (2016). How is high school greenness related to students' restoration and health? *Urban Forestry and Urban Greening*, *16*, 1–8. https://doi.org/10.1016/j.ufug.2016.01.007

Astell-Burt, T., Mitchell, R., & Hartig, T. (2014). The association between green space and mental health varies across the lifecourse. a longitudinal study. *Journal of Epidemiology and Community Health*, *68*(6), 578–583. https://doi.org/10.1136/jech-2013-203767

Bakolis, I., Hammoud, R., Smythe, M., Gibbons, J., Davidson, N., Tognin, S., & Mechelli, A. (2018). Urban Mind: Using Smartphone Technologies to Investigate the Impact of Nature on Mental Well-Being in Real Time. *BioScience*, *68*(2), 134–145. https://doi.org/10.1093/biosci/bix149

Bernard, H. R., Killworth, P., Kronenfeld, D., & Sailer, L. (1984). The problem of informant accuracy: the validity of retrospective data. *Annual Review of Anthropology. Vol. 13*, 495–517. https://doi.org/10.1146/annurev.an.13.100184.002431

Britton, E., Kindermann, G., Domegan, C., & Carlin, C. (2018). Blue care: a systematic review of blue space interventions for health and wellbeing. *Health Promotion International*, 1–20. https://doi.org/10.1093/heapro/day103

Cale, L. (1994). Self-report measures of children's physical activity: recommendations for future development and a new alternative measure. *Health Education Journal.*, *53*(4), 439–453.

Cantril, H. (1965). *The Pattern of Human Concern*. Rutgers University Press.

Chawla, L. (2015). Benefits of Nature Contact for Children. *Journal of Planning Literature*, *30*(4), 433–452. https://doi.org/10.1177/0885412215595441

Crone, E. A., & Fuligni, A. J. (2020). Self and others in adolescence. *Annual Review of Psychology*, *71*, 447–469. https://doi.org/10.1146/annurev-psych-010419-050937

Dadvand, P., Hariri, S., Abbasi, B., Heshmat, R., Qorbani, M., Motlagh, M. E., Basagaña, X., & Kelishadi, R. (2019). Use of green spaces, self-satisfaction and social contacts in

adolescents: A population-based CASPIAN-V study. *Environmental Research*, *168*(September 2018), 171–177. https://doi.org/10.1016/j.envres.2018.09.033

Das, J. K., Salam, R. A., Lassi, Z. S., Khan, M. N., Mahmood, W., Patel, V., & Bhutta, Z. A. (2016). Interventions for Adolescent Mental Health: An Overview of Systematic Reviews. *Journal of Adolescent Health*, *59*(2), S49–S60. https://doi.org/10.1016/j.jadohealth.2016.06.020

de Bell, S., Graham, H., Jarvis, S., & 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*(May), 118–127. https://doi.org/10.1016/j.landurbplan.2017.06.003

Fredrickson, B. L. (2004). The broaden-and-build theory of positive emotions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *359*(1449), 1367–1377. https://doi.org/10.1098/rstb.2004.1512

Friedman, S., Imrie, S., Fink, E., Gedikoglu, M., & Hughes, C. (2022). Understanding changes to children's connection to nature during the COVID-19 pandemic and implications for child well-being. *People and Nature*, *4*(1), 155–165. https://doi.org/10.1002/pan3.10270

Gascon, M., Mas, M. T., Martínez, D., Dadvand, P., Forns, J., Plasència, A., & 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

Greenwood, A., & Gatersleben, B. (2016). Let's go outside! Environmental restoration amongst adolescents and the impact of friends and phones. *Journal of Environmental Psychology*, *48*, 131–139. https://doi.org/10.1016/j.jenvp.2016.09.007

Gruber, J., Clark, L. A., Abramowitz, J. S., Aldao, A., Chung, T., Forbes, E. E., Nagayama Hall, G. C., Hinshaw, S. P., Hollon, S., Klein, D. N., Levenson, R. W., McKay, D.,

Mendle, J., Neblett, E. W., Olatunji, B. O., Prinstein, M. J., Rottenberg, J., Albano, A. M., Borelli, J. L., … Weinstock, L. M. (2021). Mental Health and Clinical Psychological Science in the Time of COVID-19: Challenges, Opportunities, and a Call to Action. *American Psychologist*, *76*(3), 409–426. https://doi.org/10.1037/amp0000707

Houlden, V., Weich, S., de Albuquerque, J. P., Jarvis, S., & Rees, K. (2018). The relationship between greenspace and the mental wellbeing of adults: A systematic review. In *PLoS ONE* (Vol. 13, Issue 9). https://doi.org/10.1371/journal.pone.0203000

Huta, V., & Ryan, R. M. (2010). Pursuing Pleasure or Virtue: The Differential and Overlapping Well-Being Benefits of Hedonic and Eudaimonic Motives. *Journal of Happiness Studies*, *11*(6), 735–762. https://doi.org/10.1007/s10902-009-9171-4

Huynh, Q., Craig, W., Janssen, I., & Pickett, W. (2013). Exposure to public natural space as a protective factor for emotional well-being among young people in Canada. *BMC Public Health*, *13*(1). https://doi.org/10.1186/1471-2458-13-407

Jollife, I. T., & Cadima, J. (2016). Principal component analysis: A review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *374*(2065), 374. https://doi.org/10.1098/rsta.2015.0202

Jones, P. B. (2013). Adult mental health disorders and their age at onset. *British Journal of Psychiatry*, *202*(SUPPL. 54), 5–11. https://doi.org/10.1192/bjp.bp.112.119164

Kaplan, R., & Kaplan, S. (2002). Adolescents and the Natural Environment: A Time Out? In P. Kahn & S. Kellert (Eds.), *Children and Nature: Psychological, Sociocultural, and Evolutionary Investigations* (1st ed., pp. 227–257). The MIT Press.

Kaplan, S. (1995). The restorative benefits of nature: Toward an intergrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182.

Korpela, K. (1991). Adolescents' and adults' favourite places. In T. Niit, M. Raudsepp, & K. Liik (Eds.), *Environment and social development. Proceedings of the East-West Colloquium in Environmental Psychology* (pp. 76–83). Tallinn Padagogical Institute.

Korpela, K. M. (1992). Adolescents' favourite places and environmental self-regulation. *Journal of Environmental Psychology*, *12*(3), 249–258. https://doi.org/10.1016/S0272-4944(05)80139-2

Lakens, D. (2022). Sample Size Justification. *Collabra: Psychology*, *8*(1), 1–28. https://doi.org/https://doi.org/10.1525/collabra.33267

Li, D., Deal, B., Zhou, X., Slavenas, M., & Sullivan, W. C. (2018). Moving beyond the neighborhood: Daily exposure to nature and adolescents' mood. *Landscape and Urban Planning*, *173*(October 2016), 33–43. https://doi.org/10.1016/j.landurbplan.2018.01.009

Li, D., Menotti, T., Ding, Y., & Wells, N. M. (2021). Life course nature exposure and mental health outcomes: A systematic review and future directions. *International Journal of Environmental Research and Public Health*, *18*(10). https://doi.org/10.3390/ijerph18105146

Linley, A. P., Joseph, S., Harrington, S., & Wood, A. M. (2006). Positive psychology: Past, present, and (possible) future. *Journal of Positive Psychology*, *1*(1), 3–16. https://doi.org/10.1080/17439760500372796

Maes, M. J. A., Pirani, M., Booth, E. R., Shen, C., Milligan, B., Jones, K. E., & Toledano, M. B. (2021). Benefit of woodland and other natural environments for adolescents' cognition and mental health. *Nature Sustainability*, *4*(10), 851–858. https://doi.org/10.1038/s41893-021-00751-1

Mavoa, S., Lucassen, M., Denny, S., Utter, J., Clark, T., & Smith, M. (2019). Natural neighbourhood environments and the emotional health of urban New Zealand adolescents. *Landscape and Urban Planning*, *191*(April), 103638. https://doi.org/10.1016/j.landurbplan.2019.103638

Mayer, F. S., Frantz, C. M. P., Bruehlman-Senecal, E., & Dolliver, K. (2009). Why is nature beneficial?: The role of connectedness to nature. *Environment and Behavior*, *41*(5), 607–643. https://doi.org/10.1177/0013916508319745

McCormick, R. (2017). Does Access to Green Space Impact the Mental Well-being of

Children: A Systematic Review. *Journal of Pediatric Nursing*, *37*, 3–7. https://doi.org/10.1016/j.pedn.2017.08.027

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses : *Annals of Internal Medicine*, *151*(4), 264–269.

Mueller, M. A. E., & Flouri, E. (2021). Urban Adolescence: The Role of Neighbourhood Greenspace in Mental Well-Being. *Frontiers in Psychology*, *12*(September). https://doi.org/10.3389/fpsyg.2021.712065

Oswald, T. K., Rumbold, A. R., Kedzior, S. G. E., & Moore, V. M. (2020). Psychological impacts of " screen time " and " green time " for children and adolescents : A systematic scoping review. *PLoS ONE*, *15*(9), 1–52. https://doi.org/10.1371/journal.pone.0237725

Pritchard, A., Richardson, M., Sheffield, D., & McEwan, K. (2020). The Relationship Between Nature Connectedness and Eudaimonic Well-Being: A Meta-analysis. *Journal of Happiness Studies*, *21*(3), 1145–1167. https://doi.org/10.1007/s10902-019-00118-6

Roberts, A., Hinds, J., & Camic, P. M. (2020). Nature activities and wellbeing in children and young people: a systematic literature review. *Journal of Adventure Education and Outdoor Learning*, *20*(4), 298–318. https://doi.org/10.1080/14729679.2019.1660195

Rudolph, K. E., Stuart, E. A., Glass, T. A., & Merikangas, K. R. (2014). Neighborhood disadvantage in context: The influence of Urbanicity on the association between neighborhood disadvantage and adolescent emotional disorders. *Social Psychiatry and Psychiatric Epidemiology*, *49*(3), 467–475. https://doi.org/10.1007/s00127-013-0725-8

Ryan, R., & Deci, E. (2001). On Happiness and Human Potentials: A Review of Research on Hedonic and Eudaimonic Well-Being. *Annual Review of Psychology*, *52*, 141–166. https://doi.org/10.1146/annurev.psych.52.1.141

Ryff, C. D. (1989). Happiness is everything, or is it? Explorations on the meaning of psychological well-being. *Journal of Personality and Social Psychology*, *57*(6), 1069–1081. https://doi.org/10.1037/0022-3514.57.6.1069

Sallis, J. F. (1991). Self-report measures of children's physical activity. *Journal of School*

*Health*, *61*(5), 215–220.

Schwarz, N. (2007). Retrospective and concurrent self-reports: The rationale for real-time data capture. In A. Stone, S. Shiffman, A. Atienza, & L. Nebeling (Eds.), *The Science of Real-Time Data Capture: Self-Reports in Health Research* (pp. 11–26). Oxford University Press.

Stavraki, M., García-Márquez, R., Bajo, M., Callejas-Albiñana, A. I., Paredes, B., & Díaz, D. (2022). Brief Version of the Ryff Psychological Well-Being Scales for Children and Adolescents: Evidence of Validity. *Psicothema*, *34*(2), 316–322. https://doi.org/10.7334/psicothema2021.235

Steinberg, L., Graham, S., O'Brien, L., Woolard, J., Cauffman, E., & Banich, M. (2009). Age differences in future orientation and delay discounting. *Child Development*, *80*(1), 28–44. https://doi.org/10.1111/j.1467-8624.2008.01244.x

*Study Quality Assessment Tools*. (n.d.). National Heart, Lung, and Blood Institute. Retrieved September 26, 2019, from https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools

Theofilou, P. (2013). Quality of life: Definition and measurement. *Europe's Journal of Psychology*, *9*(1), 150–162. https://doi.org/10.5964/ejop.v9i1.337

Tillmann, S., Tobin, D., Avison, W., & Gilliland, J. (2018). Mental health benefits of interactions with nature in children and teenagers: A systematic review. *Journal of Epidemiology and Community Health*, *72*(10), 958–966. https://doi.org/10.1136/jech-2018-210436

van den Berg, A. E., Maas, J., Verheij, R. A., & Groenewegen, P. P. (2010). Green space as a buffer between stressful life events and health. *Social Science and Medicine*, *70*(8), 1203–1210. https://doi.org/10.1016/j.socscimed.2010.01.002

Wallner, P., Kundi, M., Arnberger, A., Eder, R., Allex, B., Weitensfelder, L., & Hutter, H. P. (2018). Reloading pupils' batteries: Impact of green spaces on cognition and wellbeing. *International Journal of Environmental Research and Public Health*, *15*(6).

https://doi.org/10.3390/ijerph15061205

Ward, J. S., Duncan, J. S., Jarden, A., & Stewart, T. (2016). The impact of children's exposure to greenspace on physical activity, cognitive development, emotional wellbeing, and ability to appraise risk. *Health and Place*, *40*, 44–50. https://doi.org/10.1016/j.healthplace.2016.04.015

Werner-Seidler, A., Perry, Y., Calear, A. L., Newby, J. M., & Christensen, H. (2017). School-based depression and anxiety prevention programs for young people: A systematic review and meta-analysis. *Clinical Psychology Review*, *51*, 30–47. https://doi.org/10.1016/j.cpr.2016.10.005

White, M. P., Alcock, I., Wheeler, B. W., & Depledge, M. H. (2013). Would You Be Happier Living in a Greener Urban Area? A Fixed-Effects Analysis of Panel Data. *Psychological Science*, *24*(6), 920–928. https://doi.org/10.1177/0956797612464659

World Health Organisation. (n.d.). *Adolescent Health*. World Health Organisation. Retrieved October 20, 2021, from https://www.who.int/health-topics/adolescent-health#tab=tab_1

Zhang, Y., Mavoa, S., Zhao, J., Raphael, D., & Smith, M. (2020). The Association between Green Space and Adolescents ' Mental Well-Being : A Systematic Review. *International Journal of Environmental Research and Public Health*, *17*(18), 6640. https://doi.org/10.3390/ijerph17186640

# Appendices

## Appendix A: Database Search Terms

**Scopus:**

| PECO criteria | Theme | Search terms |
|---|---|---|
| **Population** | Adolescence | (“teen”) or (“adolescent”) or (“adolescence”) or (“youth”) or (“juvenile”) or {young people} or {young person} or (“young adult”) or {lifecourse} or {life course} or {lifespan} or {life span}) |
| **Exposure** | Natural environment | ({greenspace} or (“green space”) or {green-space} or {greenness} or {greenery} or {green belt} or {green corridor} or (“natural environment”) or (“open space”) or (“park”) or (“parks”) or (“natural space”) or {naturalness} or (“garden”) or {canopy} or (“tree”) or (“forest”) or (“woodland”) or {urban nature} or {biodiversity} or (“outdoor”) or {blue space} or {bluespace} or (“coast”) or (“sea”) or (“water”) or (“river”) or (“lake”) or (“beach”) or (“ocean”) or (“marine”)) |
| **Outcome** | Psychological Wellbeing | ({wellbeing} or {well-being} or {well being} or {wellness} or {positive affect} or {restoration} or (“positive emotion”) or (“increased mood”) or (“heightened mood”) or (“improved mood”) or {happiness} or {pleasure} or {life satisfaction}) |

**Web of Science:**

| PECO criteria | Theme | Search terms |
|---|---|---|
| **Population** | Adolescence | ((teen*) or (adolescen*) or (youth*) or (juvenile*) or (“young people”) or (“young person”) or (“young adult*”) or (lifecourse) or (“life course”) or (lifespan) or (“life span”)) |
| **Exposure** | Natural environment | ((green?space) or (green NEAR/1 space*) or (green space*) or (greenspace*) or (greenery) or (green belt*) or (green corridor*) or (natural environment*) or (open space*) or (park) or (parks) or (natur* space*) or (naturalness) or (garden*) or (canopy) or (tree*) or (forest*) or (woodland*) or (urban nature) or (biodiversity) or (outdoor*) or (blue space*) or (blue NEAR/1 space) or (coast*) or (sea) or (water) or (river) or (lake) or (beach) or (ocean) or (marine)) |

| | | |
|---|---|---|
| **Outcome** | Psychological Wellbeing | (TI=(((wellbeing) OR (well-being) OR (“well being”) OR (wellness) OR (“positive affect”) OR (restoration) OR (“positive emotion*”) OR (“increased NEAR/2 mood”) OR (“heightened NEAR/2 mood”) OR (“improved NEAR/2 mood”) OR (happiness) OR (pleasure)))) OR AB=(((wellbeing) OR (well-being) OR (“well being”) OR (wellness) OR (“positive affect”) OR (restoration) OR (“positive emotion*”) OR (“increased NEAR/2 mood”) OR (“heightened NEAR/2 mood”) OR (“improved NEAR/2 mood”) OR (happiness) OR (pleasure) OR (life satisfaction) OR (“life NEAR/2 satisfaction”))) |

| **Additional Parameters** | |
|---|---|
| **Categories** | Ecology, Environmental Sciences, Public Environmental Occupational Health, Oceanography, Education Educational Research, Environmental Studies, Multidisciplinary Sciences, Psychology Multidisciplinary, Psychiatry, Social Sciences Interdisciplinary, Psychology Developmental, Social Sciences Biomedical, Neurosciences, Urban Studies, Sociology, Evolutionary Biology, Health Care Sciences Services, Psychology Clinical, Psychology, Behavioural Sciences, Health Policy Services, Regional Urban Planning, Nursing, Psychology Social, Clinical Neurology, Psychology Applied, Development Studies, Psychology Biological, Psychology Experimental, Psychology Educational, Integrative Complementary Medicine |
| **Research Areas** | Environmentl sciences ecology, Public Environmental Occupational, Biodiversity Conservation, Psychology, Oceanography, Education Educational Research, Social Sciences Other Topics, Psychiatry, Neurosciences Neurology, Biomedical Social Studies, Urban Studies, Evolutionary Biology, Sociology, Health Care Sciences Services, Social Work, Nursing, Pediatrics, Developmental Studies, Integrative Complementary Medicine, Life Sciences Biomedicine Other Topics, Developmental Biology |

## Appendix B: NHLBI Quality Assessment Tool Guidance

**Guidance for Assessing the Quality of Observational Cohort and Cross-Sectional Studies**

The guidance document below is organized by question number from the tool for quality assessment of observational cohort and cross-sectional studies.

**Question 1. Research question**

Did the authors describe their goal in conducting this research? Is it easy to understand what they were looking to find? This issue is important for any scientific paper of any type. Higher quality scientific research explicitly defines a research question.

**Questions 2 and 3. Study population**

Did the authors describe the group of people from which the study participants were selected or recruited, using demographics, location, and time period? If you were to conduct this study again, would you know who to recruit, from where, and from what time period? Is the cohort population free of the outcomes of interest at the time they were recruited?

An example would be men over 40 years old with type 2 diabetes who began seeking medical care at Phoenix Good Samaritan Hospital between January 1, 1990 and December 31, 1994. In this example, the population is clearly described as: (1) who (men over 40 years old with type 2 diabetes); (2) where (Phoenix Good Samaritan Hospital); and (3) when (between January 1, 1990 and December 31, 1994). Another example is women ages 34 to 59 years of age in 1980 who were in the nursing profession and had no known coronary disease, stroke, cancer, hypercholesterolemia, or diabetes, and were recruited from the 11 most populous States, with contact information obtained from State nursing boards.

In cohort studies, it is crucial that the population at baseline is free of the outcome of interest. For example, the nurses' population above would be an appropriate group in which to study incident coronary disease. This information is usually found either in descriptions of population recruitment, definitions of variables, or inclusion/exclusion criteria.

You may need to look at prior papers on methods in order to make the assessment for this question. Those papers are usually in the reference list.

If fewer than 50% of eligible persons participated in the study, then there is concern that the study population does not adequately represent the target population. This increases the risk of bias.

**Question 4. Groups recruited from the same population and uniform eligibility criteria**

Were the inclusion and exclusion criteria developed prior to recruitment or selection of the study population? Were the same underlying criteria used for all of the subjects involved? This issue is related to the description of the study population, above, and you may find the information for both of these questions in the same section of the paper.

Most cohort studies begin with the selection of the cohort; participants in this cohort are then measured or evaluated to determine their exposure status. However, some cohort studies may recruit or select exposed participants in a different time or place than unexposed participants, especially retrospective cohort studies–which is when data are obtained from the past (retrospectively), but the analysis examines exposures prior to outcomes. For example, one research question could be 45hether diabetic men with clinical depression are at higher risk for cardiovascular disease than those without clinical depression. So, diabetic men with depression might be selected from a mental health clinic, while diabetic men without depression might be

selected from an internal medicine or endocrinology clinic. This study recruits groups from different clinic populations, so this example would get a “no.”

However, the women nurses described in the question above were selected based on the same inclusion/exclusion criteria, so that example would get a “yes.”

**Question 5. Sample size justification**

Did the authors present their reasons for selecting or recruiting the number of people included or analyzed? Do they note or discuss the statistical power of the study? This question is about whether or not the study had enough participants to detect an association if one truly existed.

A paragraph in the methods section of the article may explain the sample size needed to detect a hypothesized difference in outcomes. You may also find a discussion of power in the discussion section (such as the study had 85 percent power to detect a 20 percent increase in the rate of an outcome of interest, with a 2-sided alpha of 0.05). Sometimes estimates of variance and/or estimates of effect size are given, instead of sample size calculations. In any of these cases, the answer would be “yes.”

However, observational cohort studies often do not report anything about power or sample sizes because the analyses are exploratory in nature. In this case, the answer would be “no.” This is not a “fatal flaw.” It just may indicate that attention was not paid to whether the study was sufficiently sized to answer a prespecified question–i.e., it may have been an exploratory, hypothesis-generating study.

**Question 6. Exposure assessed prior to outcome measurement**

This question is important because, in order to determine whether an exposure causes an outcome, the exposure must come before the outcome.

For some prospective cohort studies, the investigator enrolls the cohort and then determines the exposure status of various members of the cohort (large epidemiological studies like Framingham used this approach). However, for other cohort studies, the cohort is selected based on its exposure status, as in the example above of depressed diabetic men (the exposure being depression). Other examples include a cohort identified by its exposure to fluoridated drinking water and then compared to a cohort living in an area without fluoridated water, or a cohort of military personnel exposed to combat in the Gulf War compared to a cohort of military personnel not deployed in a combat zone.

With either of these types of cohort studies, the cohort is followed forward in time (i.e., prospectively) to assess the outcomes that occurred in the exposed members compared to nonexposed members of the cohort. Therefore, you begin the study in the present by looking at groups that were exposed (or not) to some biological or behavioral factor, intervention, etc., and then you follow them forward in time to examine outcomes. If a cohort study is conducted properly, the answer to this question should be “yes,” since the exposure status of members of the cohort was determined at the beginning of the study before the outcomes occurred.

For retrospective cohort studies, the same principal applies. The difference is that, rather than identifying a cohort in the present and following them forward in time, the investigators go back in time (i.e., retrospectively) and select a cohort based on their exposure status in the past and then follow them forward to assess the outcomes that occurred in the exposed and nonexposed cohort members. Because in retrospective cohort studies the exposure and outcomes may have already occurred (it depends on how long they follow the cohort), it is important to make sure that the exposure preceded the outcome.

Sometimes cross-sectional studies are conducted (or cross-sectional analyses of cohort-study data), where the exposures and outcomes are measured during the same timeframe. As a

result, cross-sectional analyses provide weaker evidence than regular cohort studies regarding a potential causal relationship between exposures and outcomes. For cross-sectional analyses, the answer to Question 6 should be “no.”

**Question 7. Sufficient timeframe to see an effect**

Did the study allow enough time for a sufficient number of outcomes to occur or be observed, or enough time for an exposure to have a biological effect on an outcome? In the examples given above, if clinical depression has a biological effect on increasing risk for CVD, such an effect may take years. In the other example, if higher dietary sodium increases BP, a short timeframe may be sufficient to assess its association with BP, but a longer timeframe would be needed to examine its association with heart attacks.

The issue of timeframe is important to enable meaningful analysis of the relationships between exposures and outcomes to be conducted. This often requires at least several years, especially when looking at health outcomes, but it depends on the research question and outcomes being examined.

Cross-sectional analyses allow no time to see an effect, since the exposures and outcomes are assessed at the same time, so those would get a “no” response.

**Question 8. Different levels of the exposure of interest**

If the exposure can be defined as a range (examples: drug dosage, amount of physical activity, amount of sodium consumed), were multiple categories of that exposure assessed? (for example, for drugs: not on the medication, on a low dose, medium dose, high dose; for dietary sodium, higher than average U.S. consumption, lower than recommended consumption, between the two). Sometimes discrete categories of exposure are not used, but instead exposures are measured as continuous variables (for example, mg/day of dietary sodium or BP values).

In any case, studying different levels of exposure (where possible) enables investigators to assess trends or dose-response relationships between exposures and outcomes–e.g., the higher the exposure, the greater the rate of the health outcome. The presence of trends or dose-response relationships lends credibility to the hypothesis of causality between exposure and outcome.

For some exposures, however, this question may not be applicable (e.g., the exposure may be a dichotomous variable like living in a rural setting versus an urban setting, or vaccinated/not vaccinated with a one-time vaccine). If there are only two possible exposures (yes/no), then this question should be given an “NA,” and it should not count negatively towards the quality rating.

**Question 9. Exposure measures and assessment**

Were the exposure measures defined in detail? Were the tools or methods used to measure exposure accurate and reliable–for example, have they been validated or are they objective? This issue is important as it influences confidence in the reported exposures. When exposures are measured with less accuracy or validity, it is harder to see an association between exposure and outcome even if one exists. Also as important is whether the exposures were assessed in the same manner within groups and between groups; if not, bias may result.

For example, retrospective self-report of dietary salt intake is not as valid and reliable as prospectively using a standardized dietary log plus testing participants’ urine for sodium content. Another example is measurement of BP, where there may be quite a difference between usual care, where clinicians measure BP however it is done in their practice setting (which can vary considerably), and use of trained BP assessors using standardized equipment (e.g., the same BP device which has been tested and calibrated) and a standardized protocol (e.g., patient is seated

for 5 minutes with feet flat on the floor, BP is taken twice in each arm, and all four measurements are averaged). In each of these cases, the former would get a “no” and the latter a "yes."

Here is a final example that illustrates the point about why it is important to assess exposures consistently across all groups: If people with higher BP (exposed cohort) are seen by their providers more frequently than those without elevated BP (nonexposed group), it also increases the chances of detecting and documenting changes in health outcomes, including CVD-related events. Therefore, it may lead to the conclusion that higher BP leads to more CVD events. This may be true, but it could also be due to the fact that the subjects with higher BP were seen more often; thus, more CVD-related events were detected and documented simply because they had more encounters with the health care system. Thus, it could bias the results and lead to an erroneous conclusion.

**Question 10. Repeated exposure assessment**

Was the exposure for each person measured more than once during the course of the study period? Multiple measurements with the same result increase our confidence that the exposure status was correctly classified. Also, multiple measurements enable investigators to look at changes in exposure over time, for example, people who ate high dietary sodium throughout the followup period, compared to those who started out high then reduced their intake, compared to those who ate low sodium throughout. Once again, this may not be applicable in all cases. In many older studies, exposure was measured only at baseline. However, multiple exposure measurements do result in a stronger study design.

**Question 11. Outcome measures**

Were the outcomes defined in detail? Were the tools or methods for measuring outcomes accurate and reliable–for example, have they been validated or are they objective? This issue is important because it influences confidence in the validity of study results. Also important is whether the outcomes were assessed in the same manner within groups and between groups.

An example of an outcome measure that is objective, accurate, and reliable is death–the outcome measured with more accuracy than any other. But even with a measure as objective as death, there can be differences in the accuracy and reliability of how death was assessed by the investigators. Did they base it on an autopsy report, death certificate, death registry, or report from a family member? Another example is a study of whether dietary fat intake is related to blood cholesterol level (cholesterol level being the outcome), and the cholesterol level is measured from fasting blood samples that are all sent to the same laboratory. These examples would get a “yes.” An example of a “no” would be self-report by subjects that they had a heart attack, or self-report of how much they weigh (if body weight is the outcome of interest).

Similar to the example in Question 9, results may be biased if one group (e.g., people with high BP) is seen more frequently than another group (people with normal BP) because more frequent encounters with the health care system increases the chances of outcomes being detected and documented.

**Question 12. Blinding of outcome assessors**

Blinding means that outcome assessors did not know whether the participant was exposed or unexposed. It is also sometimes called “masking.” The objective is to look for evidence in the article that the person(s) assessing the outcome(s) for the study (for example, examining medical records to determine the outcomes that occurred in the exposed and comparison groups) is masked to the exposure status of the participant. Sometimes the person measuring the exposure is the same person conducting the outcome assessment. In this case,

the outcome assessor would most likely not be blinded to exposure status because they also took measurements of exposures. If so, make a note of that in the comments section.

As you assess this criterion, think about whether it is likely that the person(s) doing the outcome assessment would know (or be able to figure out) the exposure status of the study participants. If the answer is no, then blinding is adequate. An example of adequate blinding of the outcome assessors is to create a separate committee, whose members were not involved in the care of the patient and had no information about the study participants' exposure status. The committee would then be provided with copies of participants' medical records, which had been stripped of any potential exposure information or personally identifiable information. The committee would then review the records for prespecified outcomes according to the study protocol. If blinding was not possible, which is sometimes the case, mark "NA" and explain the potential for bias.

**Question 13. Followup rate**

Higher overall followup rates are always better than lower followup rates, even though higher rates are expected in shorter studies, whereas lower overall followup rates are often seen in studies of longer duration. Usually, an acceptable overall followup rate is considered 80 percent or more of participants whose exposures were measured at baseline. However, this is just a general guideline. For example, a 6-month cohort study examining the relationship between dietary sodium intake and BP level may have over 90 percent followup, but a 20-year cohort study examining effects of sodium intake on stroke may have only a 65 percent followup rate.

**Question 14. Statistical analyses**

Were key potential confounding variables measured and adjusted for, such as by statistical adjustment for baseline differences? Logistic regression or other regression methods are often used to account for the influence of variables not of interest.

This is a key issue in cohort studies, because statistical analyses need to control for potential confounders, in contrast to an RCT, where the randomization process controls for potential confounders. All key factors that may be associated both with the exposure of interest and the outcome–that are not of interest to the research question–should be controlled for in the analyses.

For example, in a study of the relationship between cardiorespiratory fitness and CVD events (heart attacks and strokes), the study should control for age, BP, blood cholesterol, and body weight, because all of these factors are associated both with low fitness and with CVD events. Well-done cohort studies control for multiple potential confounders.

**Some general guidance for determining the overall quality rating of observational cohort and cross-sectional studies**

The questions on the form are designed to help you focus on the key concepts for evaluating the internal validity of a study. They are not intended to create a list that you simply tally up to arrive at a summary judgment of quality.

Internal validity for cohort studies is the extent to which the results reported in the study can truly be attributed to the exposure being evaluated and not to flaws in the design or conduct of the study–in other words, the ability of the study to draw associative conclusions about the effects of the exposures being studied on outcomes. Any such flaws can increase the risk of bias.

Critical appraisal involves considering the risk of potential for selection bias, information bias, measurement bias, or confounding (the mixture of exposures that one cannot tease out from each other). Examples of confounding include co-interventions, differences at baseline in patient characteristics, and other issues throughout the questions above. High risk of bias

translates to a rating of poor quality. Low risk of bias translates to a rating of good quality. (Thus, the greater the risk of bias, the lower the quality rating of the study.)

In addition, the more attention in the study design to issues that can help determine whether there is a causal relationship between the exposure and outcome, the higher quality the study. These include exposures occurring prior to outcomes, evaluation of a dose-response gradient, accuracy of measurement of both exposure and outcome, sufficient timeframe to see an effect, and appropriate control for confounding–all concepts reflected in the tool.

Generally, when you evaluate a study, you will not see a “fatal flaw,” but you will find some risk of bias. By focusing on the concepts underlying the questions in the quality assessment tool, you should ask yourself about the potential for bias in the study you are critically appraising. For any box where you check “no” you should ask, “What is the potential risk of bias resulting from this flaw in study design or execution?” That is, does this factor cause you to doubt the results that are reported in the study or doubt the ability of the study to accurately assess an association between exposure and outcome?

The best approach is to think about the questions in the tool and how each one tells you something about the potential for bias in a study. The more you familiarize yourself with the key concepts, the more comfortable you will be with critical appraisal. Examples of studies rated good, fair, and poor are useful, but each study must be assessed on its own based on the details that are reported and consideration of the concepts for minimizing bias.

## Appendix C: PRISMA Checklist

### PRISMA 2009 Checklist

| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| **TITLE** | | | |
| Title | 1 | Identify the report as a systematic review, meta-analysis, or both. | 7 |
| **ABSTRACT** | | | |
| Structured summary | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number. | 7 |
| **INTRODUCTION** | | | |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. | 10 |
| Objectives | 4 | Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS). | 12 |
| **METHODS** | | | |
| Protocol and registration | 5 | Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number. | 11 |
| Eligibility criteria | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. | 11/12 |
| Information sources | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched. | 12/13 |
| Search | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | 13 |
| Study selection | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis). | 14/15 |
| Data collection process | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. | 14 |
| Data items | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made. | 21-26 |
| Risk of bias in individual studies | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. | 14/21 |
| Summary measures | 13 | State the principal summary measures (e.g., risk ratio, difference in means). | 21-26 |
| Synthesis of results | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$) for each meta-analysis. | 21 |

## PRISMA 2009 Checklist

| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| Risk of bias across studies | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). | 16-19 |
| Additional analyses | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. | N/A |
| **RESULTS** | | | |
| Study selection | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram. | 15 |
| Study characteristics | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations. | 15 |
| Risk of bias within studies | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). | 21 & 20 |
| Results of individual studies | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot. | 16-19 |
| Synthesis of results | 21 | Present results of each meta-analysis done, including confidence intervals and measures of consistency. | N/A |
| Risk of bias across studies | 22 | Present results of any assessment of risk of bias across studies (see Item 15). | 21 |
| Additional analysis | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). | NA |
| **DISCUSSION** | | | |
| Summary of evidence | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers). | 25/26 |
| Limitations | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). | 21-26 |
| Conclusions | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research. | 26-32 |
| **FUNDING** | | | |
| Funding | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. | N/A |

*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: www.prisma-statement.org.

## Appendix D: PloS ONE Submission Guidance for Sytematic Literature Reviews

### Systematic reviews and meta-analyses

A systematic review paper, as defined by The Cochrane Collaboration, is a review of a clearly formulated question that uses explicit, systematic methods to identify, select, and critically appraise relevant research, and to collect and analyze data from the studies that are included in the review. These reviews differ substantially from narrative-based reviews or synthesis articles. Statistical methods (meta-analysis) may or may not be used to analyze and summarize the results of the included studies.

Reports of systematic reviews and meta-analyses should include a completed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist and flow diagram to accompany the main text. Blank templates are available here:

- Checklist: PDF or Word document
- Flow diagram: PDF or Word document

Authors must also state in their “Methods” section whether a protocol exists for their systematic review, and if so, provide a copy of the protocol as supporting information and provide the registry number in the abstract.

If your article is a systematic review or a meta-analysis you should:

- State this in your cover letter
- Select “Research Article” as your article type when submitting
- Include the PRISMA flow diagram as Fig 1 (required where applicable)
- Include the PRISMA checklist as supporting information

See Appendix H in Empirical Paper for more detailed generic guidelines.

.

**SCHOOL OF PSYCHOLOGY**

**DOCTORATE IN CLINICAL PSYCHOLOGY**

**EMPIRICAL PAPER**

# The Association Between Contact with Natural Features and Momentary Psychological Wellbeing: Do Individual Characteristics Make a Difference?


| | |
|---|---|
| Trainee Name: | **Eva Nielsen** |
| Primary Research Supervisor: | **Professor Celia Morgan**<br>Professor of Psychopharmacology, School of Psychology, University of Exeter |
| Secondary Research Supervisor: | **Dr Nick Moberly**<br>Senior Lecturer, School of Psychology, University of Exeter |
| Target Journal: | PloS ONE |


**Submitted in partial fulfilment of requirements for the Doctorate Degree in Clinical Psychology, University of Exeter**

**Acknowledgements**

I would like to thank all those who took the time to participate in this study. I would also like to thank my supervisors Celia Morgan and Nick Moberly for all their advice and support, as well as Dr Jenn Lay for her patience and sharing of knowledge in multi-level modelling. Additionally, I wish to thank my partner for all his support and for keeping our household running in my absence.

**Abstract**

***Objective:*** Potential associations between natural environments and psychological wellbeing could have important clinical implications both for improving treatment of common mental health disorders and for preventative mental health more generally. Although research has increased within the field, inconsistent methodologies have generated inconsistent results, with little attention paid to individual characteristics, such as age, gender, and symptoms of anxiety and depression. The current study aimed to address some of these issues by investigating associations between contact with natural features and momentary subjective psychological wellbeing in a non-clinical sample of those aged 16 and over, investigating whether the association differed according to aforementioned individual characteristics.

***Methods:*** 74 participants aged 16+ from non-clinical populations participated in the study, completing a 14-day smart-phone based ecological momentary assessment (EMA) period evaluating reported contact with natural features and momentary subjective psychological wellbeing alongside pre- and post-questionnaires assessing PHQ-8 and GAD-7 scores, demographic variables, and impact of COVID-19 (due to the recruitment period).

***Results:*** Positive associations between contact with natural features and psychological wellbeing were found over and above individual characteristics and potential confounding variables. Anxiety and depression symptoms were not found to moderate this association, nor did age. Gender had some impact, with men showing stronger wellbeing associations with higher numbers of natural features.

***Conclusion:*** The study builds on evidence of positive nature-wellbeing associations whilst accounting for individual characteristics. Although sample and methodological issues must be noted, it indicates that nature-wellbeing associations hold over and above individual characteristics, demonstrating the potential for its inclusion in interventions and preventative mental health recommendations.

## Introduction

It is predicted that 68% of the world's population will live in urban areas by 2050 (DESA, 2018). As we move further away from incidental exposure to natural features within our immediate environments, the need to clarify the potential health and wellbeing benefits of nature exposure becomes ever more important if we are to continue reaping them.

Policies and recommendations promoting nature-based interventions have become increasingly common, often without the necessary evidence backing them (Britton et al., 2018; Houlden et al., 2018; Norwood et al., 2019). It is only in the last ten to fifteen years that empirical research has gathered momentum in quantifying this association. Research across a range of disciplines is being used to inform urban planning, environmental policy, and public health, as well as more specific medical, social, and psychological interventions (Britton et al., 2018; Gascon et al., 2015; Masterton et al., 2020; Norwood et al., 2019)

Numerous pathways have been suggested to account for the benefits of nature, which Markevych et al. (2017) divided into the three biopsychosocial domains of reducing harm, building capacities, and restoring capacities. Reducing harm refers to natural environments being associated with less harmful factors including air and noise pollution (Dadvand et al., 2015; Dzhambov & Dimitrova, 2015; Hirabayashi & Nowak, 2016) and protection from heat (Bowler et al., 2010). Building capacities refer to more tangible benefits of nature including increased social cohesion (M. M. van den Berg et al., 2019) and physical activity (Cohen-Cline et al., 2015). Restoring capacities include the commonly cited biophilia related mechanisms, which is the innate affinity between humans and nature (Wilson, 1993). These include stress-restoration (Ulrich et al., 1991) and attention restoration theories (Kaplan, 1995) by which nature appears to have direct restorative effects on the nervous system (MacKerron & Mourato, 2013).

Its potential for clinical psychology intervention is far-reaching. Psychological associations with natural environment exposure have included improved mental health (M. M. van den Berg et al., 2019), reduced incidence of anxiety and depression (Gascon et al.,

2018; J. Maas et al., 2009), lower risk of mental illness (Engemann et al., 2019; Kobau et al., 2011), lowered risk of suicide (Helbich et al., 2018), and better psychological wellbeing (Chawla, 2015; Gascon et al., 2015, 2017; McCormick, 2017).

Clinically, psychological wellbeing has become a strong focus of research (Huppert, 2009; Tennant et al., 2007) and practice. Wellbeing is thought to encompass both hedonic happiness and pleasure components and eudaimonic components - purpose and fulfilling potential (Ryan & Deci, 2001), and is a measure of positive mental health (Houlden et al., 2018). Positive psychology has long been a proponent of clinical psychology moving beyond alleviation of suffering towards active promotion of wellbeing and life fulfilment (Duckworth et al., 2005), with health defined more broadly than simply absence of illness (Kobau et al., 2011).

Clinical psychology is increasingly mindful of wellbeing within therapeutic interventions (Slade, 2010). For example, traditional depression treatments focusing on alleviation of negative symptoms are only partially effective, with high relapse rates (Dunn, 2012). The inclusion of positive wellbeing elements is thus proposed based on depression's characteristic reductions in ability to experience and attend to positive aspects of life, alongside the increased negative affect traditionally targeted (Chaves et al., 2019). In their review of evidence for positive psychological interventions, Chaves et al. (2019) found significantly decreased depressive symptoms alongside increased wellbeing. Positive interventions, as well as supporting the building of happier, meaningful lives, can thus relieve and aid prevention of mental health disorders (Duckworth et al., 2005; Kobau et al., 2011).

The urgent need for preventative strategies within mental health has been highlighted by Owens & Bunce (2022) as a response to limited treatment efficacy and demand outstripping resources. COVID-19 and its related restrictions has and will likely continue impacting the global population's mental health for some time (e.g. Gao et al., 2020; Marroquín et al., 2020; O'Connor et al., 2021), creating increased demand for already stretched mental health services. Even prior to COVID-19, it was predicted that by 2030 an

additional two-million UK adults will have mental health problems (The Mental Health Policy Group, 2015). In the context of historical mental health under-funding, as well as likely lack of additional funds as governments strive to redress the pandemic's financial burden, clinical psychology will need to incorporate innovative, resource-low interventions to meet such need (Gruber et al., 2021). Call to arms papers have been published in COVID-19's wake advocating for interventions promoting wellbeing at public-health level (Gruber et al., 2021; Holmes et al., 2020), including nature-based interventions (Gruber et al., 2021).

Further, In 2015 only 25% of adults with symptoms of anxiety and depression received any treatment (The Mental Health Policy Group, 2015), highlighting the need for strategies to improve access to mental healthcare (Versluis et al., 2016). The World Health Organization (2021) advocated development of self-help strategies using electronic and mobile technologies, including ecological momentary interventions (EMIs) (Versluis et al., 2016). EMIs are interventions which can be delivered via mobile devices during individuals' daily lives (Heron & Smyth, 2010). Although in their infancy, they have shown great potential, demonstrating small to medium positive effects on mental health (Versluis et al., 2016), including reductions in depression and anxiety (Schueller et al., 2017). They could be especially useful for those unlikely to seek or be granted access to face-to-face treatment (Gründahl et al., 2020), such as those with milder symptoms (Versluis et al., 2016). Their use within daily life, rather than clinical settings, not only reduces costs and increases access, but also enables strategies to be learnt within situations they naturally occur (Versluis et al., 2016).

To enable efficacious development of such interventions, research into the impact of day-to-day variables on mental health and wellbeing is needed to clarify potential intervention targets. Ecological Momentary Assessment (EMA, Shiffman et al., 2008) studies have started this, enabling assessment of wellbeing at multiple time points, capturing its variability within natural contexts and allowing detection of patterns to inform wellbeing-increasing interventions (de Vries et al., 2021). Use of EMA to research the nature-wellbeing

association has so far shown positive results (Bakolis et al., 2018; de Vries et al., 2021; McEwan et al., 2020). A large-scale EMA study by MacKerron & Mourato (2013) found strong evidence that their 20,000 participants were happier in natural environments.

Research investigating nature's association with psychological wellbeing in general, however, has yielded inconsistent results. A systematic literature review investigating life-course effects of nature exposure by Li et al. (2021) found studies investigating subjective wellbeing had the most inconsistent findings. Preuß et al. (2019), for example, found reported vitality (a wellbeing measure) in adulthood was not associated with higher perceived childhood nature exposure, although better mental health was. Maes et al. (2021) found that although greenspace exposure was associated with improved cognitive development in adolescents, there was only weak association with wellbeing. Other studies have found clearer links between nature exposure and mental wellbeing (Feng & Astell-Burt, 2017; McCormick, 2017), with a meta-analysis by McMahan and Estes (2015) demonstrating moderate association between brief natural environment contact and higher positive affect.

The COVID-19 pandemic provided an opportunity to investigate the association between exposure to natural environments and psychological wellbeing during a time where other aspects of normal life were severely limited. People were exposed to a time of unprecedented restriction and uncertainty relatively unknown in present-day western societies. Lockdown procedures of differing severity were put in place around the world. In the UK, the strictest level of lockdown meant freedom of movement was restricted, most people were unable to attend workplaces, and most shops, restaurants, and leisure facilities were closed (Day, 2020). People were, however, permitted to engage in one outdoor exercise activity per day within walking distance.

Several studies have already been published investigating use of greenspaces and nature contact on wellbeing during lockdowns. It has been shown that, where allowed, people spent more time in nature, whether in gardens or public spaces (Day, 2020;

Friedman et al., 2022). In the UK, when restrictions eased to allow driving to desired locations and unlimited exercise, use of outdoor spaces greatly increased, an increase that remained even with further freeing of restrictions (Day, 2020). People have even reported renewed appreciation for greenspaces in the pandemic's wake (Royal Society for the Protection of Birds, 2020)

Nature contact and views were found to be associated with reduction in the pandemic's negative impact (Friedman et al., 2022), helping people cope with lockdown measures, especially where particularly strict (Pouso et al., 2020). Even when controlling for socio-economic factors, garden owners were found to self-report greater levels of wellbeing than non-garden owners during initial restrictions in Germany (Lehberger et al., 2021), although the amount of time spent outside, regardless of whether this was in public greenspace or private garden, was found to be most important. Overall, nature was found to be an important buffer to COVID-19's negative implications.

Under more typical conditions, nature is freely accessible to most. "Green prescriptions", if found to effectively improve psychological wellbeing, could therefore be an extremely useful burden-less intervention. Indeed, it has been suggested that even brief nature exposure can positively influence subjective wellbeing (McMahan & Estes, 2015), indicating its quick and easy efficacy.

To ensure maximum efficacy, however, we need to know what types of natural features or environments work for which people when. There is some evidence indicating that nature benefits different people to differing extents. In a relatively young sample (66% younger than 35, 95% younger than 50), MacKerron & Mourato (2013) found older people experienced a significantly larger positive association between being outdoors and subjective wellbeing in their large-scale study using experience sampling method. Bos et al. (2016), in an online questionnaire study with 4,924 participants, investigated the association between greenspace within a 3 km buffer of participants' postcodes, psychopathology, and quality of life. Their results indicated that within this buffer, the greenspace-mental health

association was different for people of different age groups and gender, although gender differences were only significant for psychopathology. Women in the youngest (18-24) and oldest (>65) age groups showed the largest effect sizes, but both men and women only showed reduction in psychopathology for these age categories.

Astell-Burt et al. (2014) found age and gender variations in the association between neighbourhood green space and mental health in their large-scale study using the British Household Panel Survey (1996-2004). Using a sample including 35,781 female and 29,626 male observations, men were found to have strongest associations between greenspace and better mental health in early adulthood, peaking at 40. Women showed most benefit from age 41 upwards.

The apparently more common finding that nature-wellbeing associations are stronger in older participants could mirror that of wellbeing in general, with the inverted u-shape commonly cited to demonstrate higher wellbeing earlier and later in life (Lansford, 2018). Perhaps the stronger association thus reflects a stronger propensity towards greater wellbeing in later life.

Findings have been generally inconsistent for both gender and age differences. For gender more broadly, some studies have illustrated more positive effects of green space for men in relation to mental (Astell-Burt et al., 2014) and physical health (Richardson & Mitchell, 2010), and for women in self-reported wellbeing (MacKerron & Mourato, 2013). Some have found variation depending upon the outcome measured (Bos et al., 2016). Raanaas et al. (2012), for example, found blocked window views in rehabilitation centre rooms appeared to negatively affect physical health for women, but mental health for men. Others have found no differences (Jiang et al., 2016). Explanations for gender differences have included potential variation in perceptions of safety and greenspace quality, more important for women (Richardson & Mitchell, 2010), alongside reason for greenspace use, and type of outcome measure, i.e. physiological response (men) versus self-report (women) (Bos et al., 2016).

Socio-economic status (SES) is frequently cited as another potential moderator of the nature-wellbeing link, with several studies citing lower SES as a barrier to nature access (Burnett et al., 2021; Friedman et al., 2022; Zhang et al., 2020) but also a predictor of increased benefits (Li et al., 2021; J. Maas et al., 2009; Twohig-Bennett & Jones, 2018; Wheeler et al., 2012). These associations may be biased by underrepresentation of participants from low SES backgrounds within the research, however (Oswald et al., 2020), with the true influence of SES remaining unclear.

Another area of inconsistency is the nature relationship for those with mental health problems. Cohen-Cline, Turkheimer, and Duncan (2015) found a significant inverse association between neighbourhood green space and depression, with more green space associated with lower depression levels. No significant associations with anxiety were found. Cox et al. (2017) found evidence suggesting those with mental illness symptoms in the mild-moderate ranges gained the greatest benefits of neighbourhood vegetation. They suggested people with severe levels may be less likely to go outside and engage with nature, but also that benefits of nature may be reduced by mechanisms behind their depression. Clinically, depression includes decreased activity and reduced interest in things around you (*ICD-10 Version:2016*, n.d.). People may feel worse when they have not engaged with nature but struggle to motivate themselves to engage when feeling worse. The aetiology of depression is multi-faceted (Bondy, 2002) but it could also be speculated that the association between negative affect and ruminative self-focus (Moberly & Watkins, 2008) may reduce the ability to notice surroundings when severely depressed.

Generally, methodological inconsistencies have precluded definite conclusions around the nature-wellbeing link. Houlden et al. (2018) conducted a systematic review investigating relationships between greenspace and mental wellbeing. In this review, they found only 14 out of 52 studies investigated both hedonic and eudaimonic wellbeing, typically utilising the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS), whilst the rest assessed only wellbeing aspects. Heterogeneity in measures, greenspace definitions,

and design meant they struggled to draw conclusions other than suggesting an association between greenspace and mental wellbeing, with the cross-sectional nature of most studies preventing causality conclusions.

Numerous gaps in knowledge also remain, with further research required into variations according to environment and ecological feature type (Bakolis et al., 2018), and individual characteristics (Bratman et al., 2015). Most studies so far have used cross-sectional, rather than longitudinal or experimental designs (Bakolis et al., 2018; Helbich et al., 2018), with momentary experience rarely investigated. They have also been limited by methodological issues, such as response and sampling bias (Chawla, 2015; Keniger et al., 2013), and inconsistent inclusion of validated outcome measures (Britton et al., 2018).

Bakolis et al. (2018) began addressing some of these difficulties through their research using EMA via a smartphone app Urban Mind to assess momentary wellbeing associations with different ecological features whilst taking individual characteristics into account. This gathered multiple measurements for participants over one week, measuring exposure to -and association between- contact with natural features and momentary psychological wellbeing within daily life. Significant positive associations were found between momentary wellbeing and being outdoors, feeling in contact with nature, and exposure to specific natural features: trees, birds, and sky.

Although overall natural environments have been found to have beneficial effects on mental health and wellbeing, research remains limited in relation to individual differences including age and mental illness symptoms. For intervention and recommendations to be meaningful, differing needs of differing populations must be explored, with continuing use of general population data risking assumption and overgeneralisation of potential benefits (Astell-Burt et al., 2014). Clarification of these factors is crucial to the efficacy of already popular nature-based clinical interventions. Whether they can be efficacious for those with symptoms of mental illness is especially relevant if interventions are to help address current treatment gaps. If, for example, the association weakens with higher anxiety and depression

symptoms, it would not be efficacious nor ethical to prescribe nature exposure to those with high levels. It may even have a negative impact if people fail to reap the benefits expected.

As such, the current study will build on that of Bakolis et al. (2018) using an EMA app to investigate associations between contact with natural features and momentary psychological wellbeing, paying particular attention to potentially moderating factors of age, gender, and depression and anxiety symptoms. Participant activity between assessments will be included as an additional confounding variable, as this was overlooked in Bakolis et al. (2018). A two-week period will be used to allow more longitudinal data collection, enabling stabilisation of responses and minimising influence of exceptional days/moments.

**Aims, Hypotheses, and Research Questions**

The study aim is to investigate the association between contact with natural features (trees, birds, sky, water) and momentary subjective psychological wellbeing in a non-clinical sample of those aged 16 and over, investigating whether there is a difference in association according to age, gender, and symptoms of anxiety and depression. Whether differences can be seen in relation to COVID-19 lockdown restrictions is also investigated. The research questions are:

1. Is contact with natural features associated with improved wellbeing?
2. Does the hypothesised association between natural feature contact and wellbeing differ when individual characteristics are accounted for?
3. Does the hypothesised association between natural feature contact and wellbeing remain when controlling for activities engaged in between ecological momentary assessments?

Exploratory research questions:

4. Were subjective experiences of Covid-19 (COVID-impact) related to variation in the contact with natural features-wellbeing association?
5. Is the degree to which participants felt in contact with nature (felt nature contact) associated with improved wellbeing?

6. Will there be a difference in depression, anxiety, and Covid-impact scores following the EMA period and will this be influenced by recruitment group?

Hypotheses:

1. In line with previous findings, e.g. Bakolis et al. (2018), self-reported daily ratings of wellbeing (using the adapted Warwick-Edinburgh Mental Well-Being Scale) were predicted to be higher when in contact with natural features, as assessed by participants being asked whether they could see/hear trees, water, sky, and/or birds at that moment.
2. It was hypothesised there would be variation in the above predicted association between natural feature contact and wellbeing according to age, gender, income-level, and, tentatively, level of depression and/or anxiety symptoms. Specifically:
    - For Age, in line with MacKerron and Mourato, (2013), Bos et al. (2016), and general wellbeing life-course patterns, the association was expected to be stronger for older participants.
    - For Gender, in line with self-report wellbeing findings of MacKerron and Mourato (2013), it was expected those identifying as women would show a stronger association than men.
    - In terms of Income-level, the association was expected to be stronger for those with a household income below the UK median. This would be consistent with findings of increased nature benefits for those with lower socio-economic status (Li et al., 2021; J. Maas et al., 2009; Twohig-Bennett & Jones, 2018; Wheeler et al., 2012).
    - Finally, it was tentatively hypothesised that stronger positive associations between natural feature contact and wellbeing would be seen in those with fewer symptoms of anxiety and depression. These findings would be in line with those of Cox et al. (2017).

3. It was hypothesised that improved wellbeing would be associated with participants having engaged in exercise, had contact with people, and/or having been outside since the last EMA. This is in line with general consensus around the positive impacts on wellbeing of each of these activities (e.g. Hyde et al., 2013; Sandstrom & Dunn, 2014). It was tentatively hypothesised, however that the association between contact with natural features and wellbeing would remain even when controlling for these factors.

Exploratory research question hypotheses:

4. It was tentatively hypothesised there would be an influence of COVID-impact scores on the strength of association between nature exposure and wellbeing. It was unclear how this would manifest due to limited evidence.
5. In line with studies citing the importance of felt connection with nature for wellbeing associations (Capaldi A. et al., 2014), it was hypothesised that improved wellbeing would be associated with feeling more in contact with nature, as assessed by asking participants to rate how in contact with nature they felt at that moment.
6. It was tentatively hypothesised that the EMA period would be associated with reduced anxiety, depression, and Covid-impact scores in line with findings around EMAs acting as interventions in themselves (J. S. Cohen et al., 2013). In line with previous studies investigating the influence of nature contact and during COVID-19 related restrictions (e.g. Friedman et al., 2022), it was hypothesised that a stronger reduction in anxiety, depression, and Covid-impact scores would be seen for the Winter21 recruitment group, due to stricter restrictions being in place. It was hypothesised that contact with natural features would thus be more important and have a stronger association with wellbeing.

## Method

### Design

A mixed between-groups and repeated-measures design was used. Ecological momentary assessments (EMAs) were conducted three times per day for a 14-day period following initial set-up and consent using a smartphone app designed by the researcher on the LifeData platform (https://www.lifedatacorp.com/). These EMAs enabled investigation of within-participant associations between contact with environmental natural features and momentary subjective psychological wellbeing. Participants were recruited in two time periods, the first between July and September 2020 (Summer2020) and the second between February and March 2021 (Winter2021). These time periods corresponded to different stages of COVID-19 related restrictions, allowing between-group comparisons to be made. The Summer2020 group were in a period of eased restrictions. Non-essential shops, restaurants, pubs etc had reopened and social distancing rules eased. The Winter2021 group experienced a period of lockdown, where a 'Stay at home' order was reinstated, and schools and non-essential businesses were closed.

**Participants and Recruitment Procedure**

Ninety-two participants were initially recruited via social media (Facebook page, Instagram account, posts to Facebook local community group), researcher contacts, and School of Psychology university newsletters. Social media recruitment consisted of development of an Instagram account specifically for the project. This was targeted at wellbeing and mental health-related accounts, as well as shared by the main researcher's contacts to gain traction. A Facebook group was also developed and shared by researcher contacts and within the university of Exeter newsletter. A link to this was also posted to a local community page covering a seaside town. Messages received via social media were responded to promptly, with participant information forms being sent out on receipt of an email address. Recruitment for the Summer2020 and Winter 2021 groups will have varied to a degree, as the main researcher was not involved in sharing the pages and the Instagram account was not used for the Winter recruitment. This meant the people sharing the study information will have been different, so the audience will have altered to some degree. The

university contacts and methods remained the same, however. Seasonal factors may also have influenced the recruitment groups, as the weather was warmer for the Summer2020 group, which may have influenced motivation to take part in a study relating to nature. All participants were UK based, so all were within the UK time zone during the assessment period.

Two participants withdrew from the study after initially starting the assessment period. A further 16 participants were excluded from the study due to incomplete data sets, self-isolation during the assessment, failure to give age or income details, or responding to less than 20 EMAs in line with Jaso et al.'s (2021) finding that 20-25 EMAs are required to produce stable estimates of affective variability, with fewer required for multilevel modelling. Three participants completed the assessment period without the final Qualtrics questionnaire. Their data was preserved, as they had completed the EMA period.

This left 74 participants in total, 40 recruited in the Summer period and 34 recruited in the Winter lockdown. Participants were aged between 19 and 66 years (M = 34.38, SD = 14.22). 72% of participants stated they were female (n = 53), with the remainder male. No other genders were reported. Participants were required to be fluent English speakers and 16 years old or over to ensure they could consent to their own participation.

As compensation, participants were awarded Amazon vouchers on completion of the final survey. To encourage higher response rates, the value differed accordingly, with £20 for completion of 90%+ of the assessments, £10 for 75-89%, and £5 for less than 75%.

Ethical approval was granted by the University of Exeter Psychology Ethics Committee (appendix A). If participants scored in the “severe” ranges for symptoms of depression and anxiety, they were presented with an additional debrief information sheet informing them they had scored in the high ranges and recommending they seek support from their GP or Depression and Anxiety service, alongside links to charities and services they may find helpful. They were reminded they could withdraw from the study at any point.

**Measures**

On expression of interest, participants were sent electronic copies of the information sheet and consent form. Following completion of the consent form, participants were sent a link to the initial online survey hosted on Qualtrics.com (May 2020). This included an additional presentation of the information sheet and consent questions followed by demographic questions, variables with potential confounding or additional effects, anxiety and depression symptom measures, and COVID-19 related items. The included measures can be found below.

***Demographic Variables***

Demographic information included gender, age, occupation, educational attainment, household income, own and familial mental health history, and whom participants lived with. Household income was computed into Income-level for the analyses by dividing responses into those above and below UK median household income rounded up from £29,900 to £30,000 (Office for National Statistics (Institution), 2021). This provided a measure of economic status, used as a crude proxy for SES.

***COVID-19 (Appendix B)***

Seven COVID-19 related questions were included to assess its subjective level of impact. For the current study three items were averaged to produce mean COVID-impact scores for the pre-EMA survey. These included how much Covid-19 was affecting participants' lives, how anxious they felt about it, and how much it was affecting their social lives. Each of these were answered using a five-point Likert scale ranging from "Not at all" to "A great deal". Whether participants were isolating or not was used as an exclusion criterion, as isolation likely meant the person would not have been outside.

***The Patient Health Questionnaire (PHQ-8, Kroenke et al., 2009)***

Symptoms of depression were assessed using the PHQ-8. Kroenke and Spitzer (2002) found the PHQ-8 to have similar predictive success and operating characteristics to the PHQ-9, demonstrated to be reliable with high internal consistency ($\alpha = .89$) and valid as a measure of depression symptom severity (Kroenke et al., 2001). The PHQ-8 omits the

ninth item asking how often respondents have had “Thoughts that you were better off dead or of hurting yourself in some way”. As the survey was conducted online, further probing or support around expressed risk was not possible (Kroenke & Spitzer, 2002). It would therefore have been unethical to include this statement.

Respondents rate how often they have experienced eight depression-related symptoms over the previous two weeks according to a four-point scale of “not at all” “several days”, “more than half the days”, or “nearly every day”, with scores of 0-3 being assigned accordingly. Recommended severity categories are 5-9 for mild, 10-14 for moderate, 15-19 for moderately severe, and 20-24 for severe (Kroenke et al., 2001).

***GAD-7 (Spitzer et al., 2006)***

Level of anxiety symptoms were assessed using the GAD-7, a seven-item measure of Generalised Anxiety Disorder found to have good internal consistency (α = .92) and validity (Spitzer et al., 2006). Respondents rate how often they have experienced symptoms included in seven statements over the previous two weeks using options of “not at all”, “several days”, “more than half the days”, or “nearly every day”. Options are assigned scores of 0-3, which are totalled to indicate overall severity level of anxiety symptoms. Spitzer et al. (2006) recommend cut-off points of 5-9 for mild, 10-14 for moderate, and 15-21 for severe anxiety symptoms

***Warwick Edinburgh Mental Well-being Scale (WEMWBS, Tennant et al., 2007)***

The WEMWBS is a measure of positive mental health shown to be reliable and have high internal consistency (α = .91), as well as good face and content validity (Tennant et al., 2007). It is a 14-item scale where participants rate their experiences over the past two-weeks of statements, such as “I’ve been thinking clearly”, along a five-point scale ranging from “None of the time” to “All of the time”. Higher scores indicate higher levels of wellbeing. The original scale was not included in subsequent analyses. Instead, an adapted version was used as the main dependent variable in the EMA phase of the study. See below for further details.

**EMA**

Procedure for the two-week EMA period can be seen in figure 1. On completion of the initial survey and LifeData download, participants were asked to email their LifeData unique code to enable linking of Qualtrics and LifeData data. Participants' 14-day assessment period started the following day.

Participants were asked to complete three assessments per day. Notifications for these were provided by the app and set to send within a 12-hour window (8am-8pm) at pseudorandom intervals, with at least two-hours between notifications. As the first assessment was worded differently due to needing no reference to previous assessments, day one was set up separately (see figure 1).

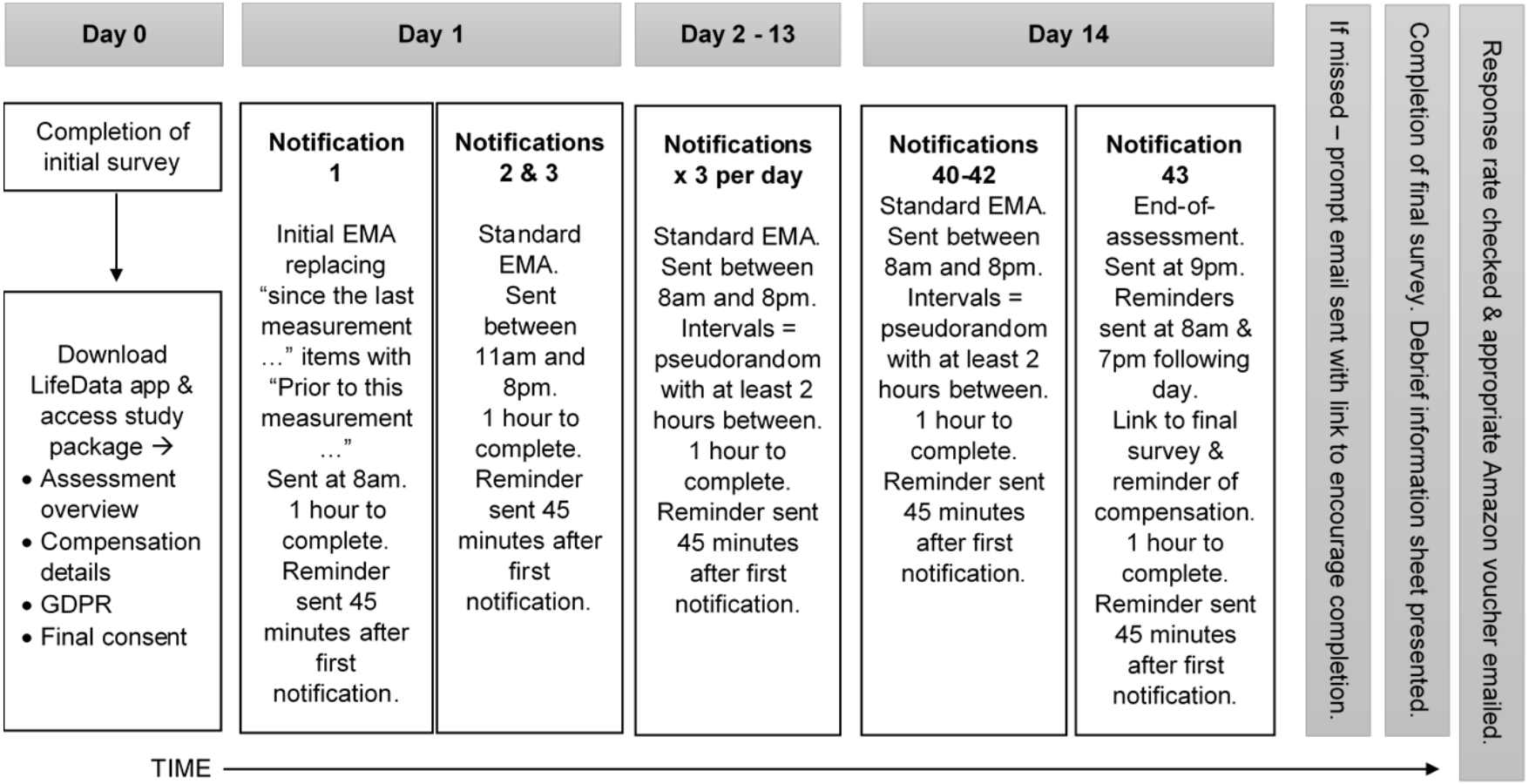
Assessments consisted of three blocks, with items within each block presented in random orders. The first block included six nature-based questions taken from Bakolis et al. (2018). These asked participants to state whether they were indoors or outdoors, if they could see trees, see sky, hear or see water, or hear birds. These items assessed momentary contact with natural features. Participants were also asked to rate how in contact with nature they felt on a sliding five-point scale from "Not at all" to "Very". This item is referred to as 'Felt Nature Contact' in the results section.

The second block was an adapted version of the WEMWBS created by Bakolis et al. (2018) to investigate momentary psychological well-being, where statements were altered to refer to the present, e.g. "Right now, I think clearly" (please see appendix C for all items). Participants rated each of the 14 statements on a five-point Likert scale (I very much disagree, I slightly disagree, not sure, I slightly agree, I very much agree). These are scored 1 to 5 respectively, with all items totalled to give an overall wellbeing score, where the higher the score, the higher the reported wellbeing. Although reliability and validity is good for the original WEMWBS (Tennant et al., 2007), this has not yet been established for the adapted version. To test reliability within this study, cronbach's alpha was calculated using the final data. The scale was found to be highly reliable ($\alpha = .94$).

The final block assessed whether participants had engaged in other activities between assessments. They were asked if they had been outside, spent time with or spoken to other people, or done any physical exercise since the last measurement. If they answered ‘yes’, further details were requested, such as time spent.

**Figure 1**

*EMA Procedure*




*Note*. This figure illustrates the EMA procedure over time, including structure of notifications and sending procedures.

## Final Qualtrics Survey

The final survey included the PHQ-8, GAD-7, COVID-19 questions adapted to relate to the assessment period, and questions assessing how typical the previous two-weeks had been. A debrief information sheet was presented at the end of the survey (appendix C).

## Statistical Analysis

### *Power Calculation*

As power calculations for multilevel models require a significant amount of unknown information, a best estimate was calculated. An initial power calculation was performed using G*Power with the tested predictor of age and additional predictors of gender and SES. Sample size for a fixed-factors linear multiple regression model was calculated using a standardised medium effect size of .15 (Cohen, 1988) due to lack of comparable study designs within existing literature. With an alpha level of .05 and power of .8, a total sample size of at least 55 participants would have been required for that model. To then calculate sample size for multilevel model analyses, the Kish formula for correction was used (1 + (n-1)*ICC, Kish, 1965). The intraclass correlation coefficient (ICC) of 0.34 was used as an estimate of average within-person correlation, as was demonstrated in a study of affect using multilevel modelling (Moberly & Watkins, 2008). Allowing for a response rate of 75%, the average number of observations (‘n’) would be 31.5. The correction factor was thus calculated as 1 + (31.5-1)*0.34 = 11.37. This was multiplied by the suggested sample size for the linear multiple regression model (55 x 11.37 = 625.35), with the outcome divided by the projected average number of observations per person (625.35/31.5) to give a minimum sample size of 20 participants (19.85), allowing for a medium effect size.

### *Main Analysis*

Missing data was checked to ensure this was not systematic. Two measures were omitted from the study due to at least half of the items having over 5% missing data, indicating these were not well understood and suggesting unreliability. These were not standardised measures, but taken from a previous study (Repke et al., 2018). All other

measures in the Qualtrics surveys had less than 5% missing data, with only one or two data points omitted. These were substituted with the measure's grand mean. Distributions were checked using histograms and box-plots. Although these indicated slight skewing for some measures, due to the relatively large sample size, these were left intact.

Due to the data being structured hierarchically, i.e. momentary assessments nested within participants, multilevel modelling was utilised. Analysis was conducted using the lme4 package in *R* (Bates et al., 2015). Multilevel models predicted momentary psychological wellbeing (adapted WEMWBS) and whether this appeared to differ with contact with natural features (trees, sky, water, and birds) as the main assessment predictor. Further extensions to the model investigated cross-level interactions of the person-level predictors on total natural feature contact-momentary psychological wellbeing slopes to assess for differences according to age, gender, income-level, pre-EMA anxiety (GAD-7) and depression (PHQ-8) symptoms, and COVID-impact. 2600 assessment points were included at the assessment-level, with 74 participants included at the person-level.

The level 1 momentary-level regression equation for the main model (Model2) used can be presented as follows:

$$Y_{ti} = \pi_{0i} + \pi_{1i}X_{1ti} + \pi_{2i}X_{2ti} + \pi_{3i}X_{3ti} + \pi_{4i}X_{4ti} + e_{ti}$$

where $Y_{ti}$ represents momentary wellbeing rating. $\pi_{0i}$ represents predicted wellbeing rating for person i when they have no natural feature contact. $\pi_{1i}$ represents predicted change in wellbeing for person i for a 1-unit increase in natural feature contact. $\pi_{2i,}$ $\pi_{3i,}$ and $\pi_{4i}$ represent predicted change in wellbeing for person i if they had done exercise ($\pi_{2i}$), spent time with people ($\pi_{3i}$), and/or been outside ($\pi_{4i}$) since the last EMA. $X_{ti}$ is the amount of natural feature contact reported. $e_{ti}$ represents the error or variation in person i's wellbeing not captured by the model.

The level 2 person-level regression equation for the intercept can be presented as follows:

$$(1)\ \pi_{0i} = \beta_{00} + \beta_{01}\, Z_{1i} + \beta_{02}\, Z_{2i} + \beta_{03}\, Z_{3i} + \beta_{04}\, Z_{4i} + \beta_{05}\, Z_{5i} + r_{0i}$$

Where $\pi_{0i}$ represents predicted wellbeing for person i when they have 0 natural feature contact (as in level 1 equation). $B_{00}$ represents average predicted wellbeing across all people when natural feature contact = 0 and age = 0. $B_{01}$ represents average predicted change in wellbeing across all people for a one-unit increase in age and $Z_i$ represents person i's age ($Z_{1i}$). $\beta_{02}$ average predicted change in wellbeing for a one-unit increase in income level (1b) and $Z_{2i}$ person I's income level. $\beta_{03}Z_{3i}$ represents the same for gender, $\beta_{04}Z_{4i}$ PHQ8 score, and $\beta_{05}Z_{5i}$ Covid-impact score. $r_{0i}$ is the error term for variation in $\pi_{0i}$ not accounted for by the model.

The level 2 person-level regression equations for the slopes can be presented as follows:

$$(2a)\ \pi_{1i} = \beta_{10} + r_{1i}$$

$$(2b)\ \pi_{2i} = \beta_{20} + r_{1i}$$

$$(2c)\ \pi_{3i} = \beta_{30} + r_{1i}$$

$$(2d)\ \pi_{4i} = \beta_{40} + r_{1i}$$

Where $\pi_{1i}$ represents predicted change in wellbeing for person i for a 1-unit increase in natural feature contact. $\beta_{10}$ is the average predicted change in wellbeing across all people for a one-unit increase in natural feature contact (2a). $\pi_{2i}$ is predicted change in wellbeing for person i for a one-unit increase in the participant engaging in exercise since the last EMA, with $\beta_{20}$ being the average predicted change across all people for the same one-unit increase. $\pi_{3i}$ and $\beta_{30}$ represent predicted change in wellbeing with one-unit increase in the person i ($\pi_{3i}$) and all people ($\beta_{30}$) being in contact with people since the last measurement. $\pi_{4i}$ and $\beta_{40}$ represent the same in relation to having been outside since the last measurement. $r_{1i}$ is the error term for variation not accounted for.

Model3 uses the same equations but $\beta_{04}Z_{4i}$ represents GAD-7 score, in place of the PHQ-8 score. Model4 again uses the same equation structure but this time all natural feature contact references are replaced with Felt Nature Contact as the main predictor variable used within this model.

Mixed ANOVAs were performed using SPSS to assess whether the EMA assessment period acted as an intervention in itself for depression and/or anxiety symptoms by comparing PHQ-8 and GAD-7 pre- and post-assessment scores by recruitment group. Pre- and post-COVID-19 impact scores were also analysed to see if there was a significant difference overall and between recruitment groups.

Total natural feature contact, age, pre-EMA PHQ-8, GAD-7 and COVID-impact scores, and exercise, seeing people, and having been outside since the last measurement variables were all centred at the grand mean. Individual natural feature contacts were also centred at the grand mean despite being categorical, as when these are not centred, within- and between-cluster effects cannot be separated, causing them to be uninterpretable (Yaremych et al., 2021). Grand mean centering was used to allow evaluation of change across the sample, regardless of individual means. It allowed investigation of whether being exposed to two natural features would be more strongly associated with wellbeing than one, for example, regardless of individuals' average number of natural features per assessment. Gender and Income-level were not centred as these were dummy coded. Maximum likelihood estimation was used for all models.

## Results

### Participants

74 participants were included in the final analyses, 40 in the Summer2020 group and 34 in the Winter2021 group. Mean response rate for included participants was 83.97%. Participant demographics can be seen in Table 1 alongside t-test or chi-square results testing for between recruitment group differences. No significant differences were found apart from for level of lockdown restrictions, with the Summer group reporting easing of restrictions compared to the full-lockdown seen in the Winter group as expected.

**Table 1.**

*Participant Demographics*

| | | Summer 2020 | Winter 2021 | t or chi square (df) | p |
|---|---|---|---|---|---|
| **N** | | 40 | 34 | - | - |
| **Age (Mean (SD))** | | 31.70 (12.68) | 37.53 (15.43) | t (63.95) = -1.76 (equal variances not assumed) | 0.08 |
| **Gender (% female)** | | 70% | 74% | $\chi^2$ (1) = 0.113 | 0.74 |
| **Household Income-level (N)** | Below median | 18 | 10 | $\chi^2$ (1) = 1.90 | 0.17 |
| | Above median | 22 | 24 | | |
| **Occupation (N)** | Student | 15 | 8 | $\chi^2$ (4) = 2.90* | 0.67 |
| | Working | 21 | 21 | | |
| | Unemployed | 3 | 3 | | |
| | Retired or unable to work | 1 | 2 | | |
| **Highest Qualification (N)** | GCSEs or equivalent | 1 | 0 | $\chi^2$ (3) = 3.38* | 0.29 |
| | A-Levels or equivalent | 9 | 14 | | |
| | Undergraduate degree | 17 | 11 | | |
| | Postgraduate degree | 12 | 9 | | |
| **Level of Covid-19 Lockdown Restrictions** | Full lockdown | 0 | 33 | $\chi^2$ (3) = 85.23* | <.001 |
| | Some easing | 10 | 1 | | |
| | Significant easing | 27 | 0 | | |
| | Little/no evidence of restrictions | 3 | 0 | | |

*Note. * = Fisher's exact test used due to uneven cell distribution.*

**Research Question One: Is Contact With Natural Features Associated With Improved Wellbeing?**

An initial multi-level model (MLM) (Model1) was performed to investigate the main effect of total natural feature contact on momentary psychological wellbeing (WEMWBS mean score for each EMA). This illustrated that the mean momentary wellbeing score was significantly higher the more natural features participants could see/hear, increasing by 0.17

for every unit increase in natural features. The proportion of variance left unexplained by Model1 was 53.4%. Comparison of Model1 to the empty model (Model 0), i.e. with no predictors included, showed that deviance was significantly reduced with inclusion of contact with natural features as a predictor (see table 2).

**Table 2.**

*Multi-level model fixed effects estimates predicting momentary WEMWBS score*

| **Variable** | **Model 0** | **Model 1** | | **Model 2** | |
|---|---|---|---|---|---|
| | Fixed Effect Estimate (Std.Error) | Fixed Effect Estimate (Std.Error) | 95% Confidence Intervals | Fixed Effect Estimate (Std.Error) | 95% Confidence Intervals |
| Intercept | 3.68 (0.07)*** | 3.69 (0.06)*** | 3.56, 3.81 | 3.88 (0.12)*** | 3.66, 4.11 |
| Total Natural Feature Contact | | 0.17 (0.02)*** | 0.14, 0.20 | 0.08 (0.03)* | 0.01, 0.14 |
| Income Level | | | | 0.008 (0.12) | -0.21, 0.23 |
| Age | | | | 0.006 (0.004) | -0.00, 0.01 |
| Gender | | | | -0.28 (0.12)* | -0.50, -0.05 |
| PHQ-8 (pre-EMA) | | | | -0.05 (0.01)*** | -0.07, -0.03 |
| Covid Impact (pre-EMA) | | | | 0.07 (0.08) | -0.08, 0.22 |
| Exercise since last measurement | | | | 0.09 (0.03)*** | 0.04, 0.14 |
| People since last measurement | | | | 0.18 (0.03)*** | 0.11, 0.24 |
| Outside since last measurement | | | | 0.12 (0.02)*** | 0.07, 0.16 |
| Between person: Average Natural Feature Contact | | | | 0.02 (0.10) | -0.17, 0.20 |
| Total Natural Feature Contact*Income | | | | -0.004 (0.03) | -0.07, 0.06 |
| Total Natural Feature Contact*Age | | | | -0.003 (0.001)* | -0.01, -0.00 |
| Total Natural Feature Contact*Gender | | | | 0.09 (0.03)** | 0.03, 0.16 |
| Total Natural Feature Contact*PHQ-8 (pre-EMA) | | | | -0.003 (0.003) | -0.01, 0.00 |
| Total Natural Feature Contact*Covid Impact (pre-EMA) | | | | 0.01 (0.02) | -0.03, 0.06 |
| Total Natural Feature Contact*Exercise | | | | -0.003 (0.02) | -0.04, 0.04 |

| | | | | |
|---|---|---|---|---|
| since last measurement | | | | |
| Total Natural Feature Contact*People since last measurement | | | -0.05 (0.03) | -0.11, -0.00 |
| Total Natural Feature Contact*Outside since last measurement | | | 0.02 (0.02) | -0.02, 0.06 |
| Total Natural Feature Contact*Average Natural Feature Contact | | | 0.008 (0.03) | -0.05, 0.06 |
| **Deviance** | 4564.9 | 4206.3*** | 4059.4*** | |
| **Chi sq** | | 358.58 | 146.92 | |
| **Degrees of freedom** | | 3 | 18 | |

*Note. * = significant at 0.05 level, ** = significant at 0.01 level, *** = significant at <0 level.*

**Research Question Two: Does the Hypothesised Association Between Natural Feature Contact and Wellbeing Differ When Individual Characteristics are Accounted for?**

Model2 was created to assess the influence of individual characteristics on the association between natural feature contact and wellbeing. This included person-level predictors of Age, Gender, Income-level, COVID-impact, and PHQ-8, with momentary-level predictors of Natural Feature Contact and exercise, people, and being outside since last measurement. Additionally, a between-person variable of average Natural Feature Contact per person was calculated and added to Model2 to account for possible between-person variations, as the main predictor being investigated. Results are seen in Table 2. The GAD-7 was not included in analyses with the PHQ-8 due to known correlation (r = .75, Spitzer et al., 2006). GAD-7 replaced PHQ-8 in an alternate model (Model3).

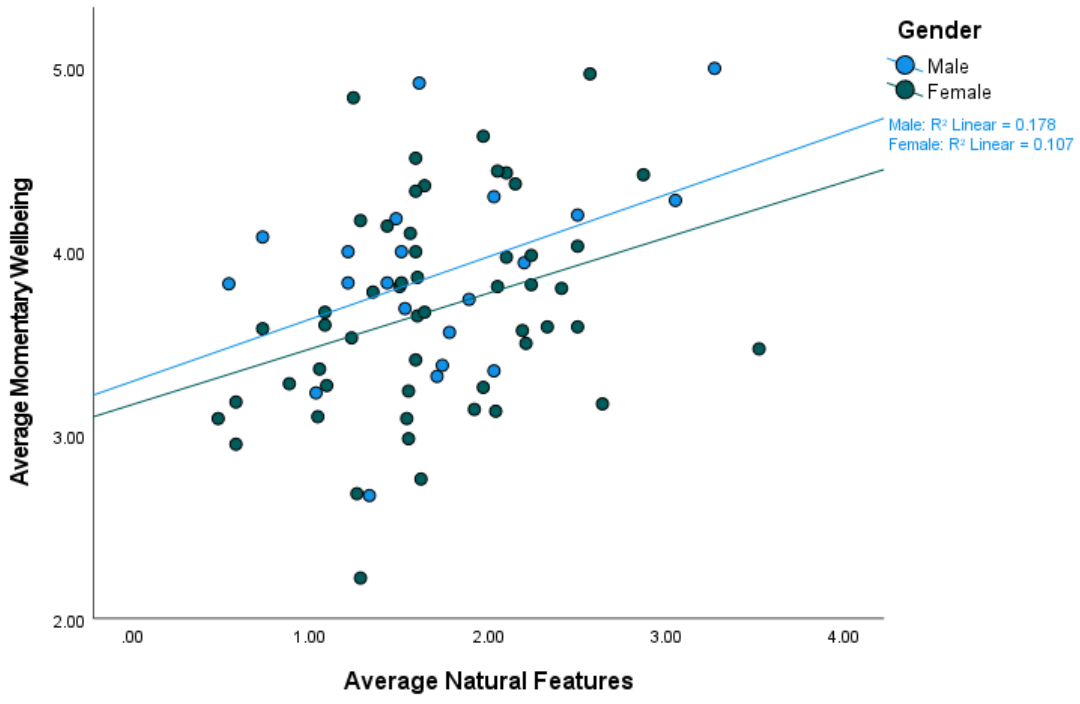
Model2 reduced the proportion of unexplained variance to 45.08%, also significantly reducing the deviance. Natural Feature Contact continued to show significant association with wellbeing, although this was reduced, with wellbeing now increasing by 0.08 units per unit increase in natural feature contact. Significant main effects of Gender and PHQ-8 were

evident, with reduced wellbeing associated with identifying as female and increased PHQ-8 scores.

The interactions of contact with natural features with both Age and Gender significantly related to wellbeing, highlighting potential moderating effects. When Age was entered into its own MLM without other predictors, however, it no longer significantly interacted with natural feature contact. Further tests investigating the influence of Age on the contact with natural features-wellbeing simple slopes revealed no significant effects. This indicates a more complex interaction of multiple variables beyond the scope of the current analyses. The Gender interaction remained significant, so an interaction plot was drawn in SPSS v26 (figure 2). This illustrated similar gender trajectories but larger divergence in wellbeing as contact with natural features increase. Men reported higher levels of momentary wellbeing with higher numbers of natural feature contact.

**Figure 2**

*Interaction plot illustrating the association between momentary wellbeing and natural feature contact by gender.*



An alternative model (Model3, table 5, appendix D) replacing PHQ-8 with GAD-7 pre-EMA scores indicated similar patterns of results, with significant main effects of GAD-7 and all 'since last measurement' variables, and a small significant effect of Natural Feature Contact. Gender and Age were non-significant as main effects but did significantly interact with Natural Feature Contact. Non-significant interaction effects for the GAD-7 and previously PHQ-8, suggest that, although they play a part in predicting the association, they do not moderate it.

**Research Question Three: Does the Hypothesised Association Between Natural Feature Contact and Wellbeing Remain When Controlling for Activities Engaged in Between Ecological Momentary Assessments?**

Model2 and Model3 indicated that wellbeing was significantly positively associated with participants having been outside, participated in exercise, and/or spent time with people since the last measurement. As previously stated, the contact with nature-wellbeing association remained significant even when controlling for these factors and individual characteristics.

**Research Question Four: Were Subjective Experiences of Covid-19 (COVID-Impact) Related to Variation in the Contact With Natural Features-Wellbeing Association?**

COVID-Impact was not found to relate significantly to the contact with natural features-wellbeing association. Non-significant main effects and interactions were found in all models (see table 2 for example).

**Research Question Five: Is the Degree to Which Participants Felt in Contact With Nature (Felt Nature Contact) Associated With Improved Wellbeing?**

To investigate whether the degree to which participants felt in contact with nature (Felt Nature Contact) was associated with wellbeing regardless of objective Natural Feature Contact (i.e. number of natural features reported), an alternative model (Model4) was run to see if this represents an alternative predictor (table 6, appendix E). In Model4, Natural Feature Contact was thus replaced by the Felt Nature Contact variable. Model4 reduced

unexplained variance to 40.7% and indicated that wellbeing also significantly increased with Felt Nature Contact (*B* = 0.19). A significant main effect of Gender indicated reduced wellbeing for women. Reduced wellbeing was also significantly associated with higher PHQ-8 scores. Increased wellbeing was significantly associated with seeing people and spending time outside since the last measurement, but not exercise. Age was non-significant and there were no significant interaction effects.

An additional further exploratory MLM assessing whether differences in contact with natural feature-wellbeing associations could be seen over time can be seen in Appendix F.

**Research Question Six: Will There be a Difference in Depression, Anxiety, and Covid-Impact Scores Following the EMA Period and Will This be Influenced by Recruitment Group?**

Mixed-ANOVAs were performed on the within-subject factor of time (pre- and post-EMA PHQ-8 and GAD-7 scores) with the between-subject factor of recruitment group (Summer2020 and Winter2021). A significant main effect of time (pre, post) was found for the PHQ-8, $F(1, 71) = 11.50$, $p = .001$, $\eta_p^2 = .14$, where scores were significantly improved (reduced) following the EMA period ($M = 13.01$, SE = 0.42, 95% CI [12.22, 13.90]) compared to prior (M = 14.33, SE = 0.57, 95% CI [13.19, 15.47]. The main effect of recruitment group was significant, $F(1, 71) = 5.57$, $p = .02$, $\eta_p^2 = .07$, with higher overall depression in the Winter2021 group, but the interaction between time and recruitment group was not, $F(1. 71) = 0.54$, $p = .82$, $\eta_p^2 = .001$. GAD-7 scores, although also improved following the EMA period (pre-EMA $M = 12.22$, SE = 0.53, 95% CI [11.17, 13.27], post-EMA $M = 11.74$, SE = 0.49, 95% CI [10.76, 12.72]), were not significant, $F(1, 70) = 1.98$, $p = .16$, $\eta_p^2 = .03$. The main effect of recruitment group ($F(1, 70) = 3.07$, $p = .08$, $\eta_p^2 = .04$) and the interaction were also non-significant, $F(1, 70) = 1.51$, $P = .22$, $\eta_p^2 = .021$.

A mixed ANOVA was also performed on pre- and post-EMA COVID-impact scores with recruitment group as the between-subject factor. This showed scores were significantly lower after the EMA (M = 2.84, SE = .09, 95% CI [2.66, 3.01] than before (M = 3.15, SE =

.08, 95% CI [2.99, 3.31]), $F(1, 71) = 21.08$, $p < .001$, $\eta_p^2 = .23$. The main effect of recruitment group was significant, $F(1, 71) = 14.43$, $p < .001$, $\eta_p^2 = .17$, with lower covid impact scores seen in the Summer2020 group (M = 2.70, SE = .11, 95% CI[2.49, 2.91]) compared to Winter2021 (M = 3.28, SE = .11, 95% CI[3.01, 3.51]). Interaction between COVID-impact and recruitment group was non-significant, $F(1,71) = .002$, $p = .97$, $\eta_p^2 = .00$.

## Discussion

A longitudinal EMA design was used to assess associations between contact with natural features and momentary subjective psychological wellbeing, taking individual differences into account. Six hypotheses were tested. It was hypothesised that contact with natural features would be associated with increased momentary wellbeing. Individual characteristics were hypothesised to make a difference to this association, with stronger associations expected for older participants, women, those with income-levels below the UK median, and those with fewer symptoms of anxiety and depression. It was hypothesised that the contact with nature-wellbeing association would remain even when controlling for participants having engaged in exercise, had contact with people, and/or having been outside in-between EMAs. It was tentatively expected there would be an influence of COVID-impact scores on the association. Finally, it was tentatively hypothesised that anxiety, depression, and COVID-impact scored would be reduced following the EMA period.

Overall, the main findings of the study were that contact with natural features was associated with higher momentary subjective psychological wellbeing (research question one). This association remained even when age, gender, income-level, covid-impact, anxiety and depression levels (research question two), seeing people, exercising, and being outdoors since the last measurement (research question three), and between-person average contact with natural features were controlled for, indicating that contact with natural features is positively associated with wellbeing over and above these.

The degree to which people felt in contact with nature was also strongly associated with wellbeing (research question five). Further investigation would be needed to compare

whether feeling in contact with nature or natural feature exposure might better explain the wellbeing association, as well as how felt nature contact might be stimulated for the purpose of intervention. Potential differences between natural feature exposure and feeling in contact with nature may be tentatively explained as a qualitative difference between passive exposure and actively noticing or feeling connected to nature. The key to nature's benefits may be people's relationship to it (Maes et al., 2021) or the value we place upon it (de Bell et al., 2017), rather than simply exposure. Further tentative evidence for this may come from increased nature-wellbeing associations seen over time, alongside reductions in PHQ-8 and COVID-impact scores pre- and post-EMAs. The reminder to notice natural features may increase participants' ability to notice or influence the quality of noticing, potentially influencing participants' wellbeing. Clinically it may be important that nature interventions include a component of paying active attention to nature, rather than simply spending time outside, a feature currently being trialled with the Schmapped app (McEwan et al., 2019).

Age was found to be minimally related to the contact with nature-wellbeing association. It did interact with natural feature contact and feeling in contact with nature, indicating some degree of association. As this was no longer apparent following removal of other predictors, a multi-faceted interaction between Age and one or more other factors is suggested but beyond the current study's scope. Lack of strong age effects may have been influenced by the minimal range of ages included, with most participants being in their twenties. A larger sample with more evenly distributed ages may have allowed clearer differences to be seen. Of particular interest would be to assess adolescents in comparison to working age and older adults, as this remains under-researched. Due to COVID-19 restrictions when commencing recruitment, it was not possible to target sixth-form colleges as planned. This could be a useful future study to inform public health guidance aimed at improving wellbeing into adulthood.

Gender differences were evident, with stronger contact with nature-wellbeing associations seen for men. This contrasted with the hypothesis but is in line with previous

findings indicating stronger greenspace-mental health associations for men (Astell-Burt et al., 2014; Raanaas et al., 2012). Previous potential explanations around perceived safety and differing greenspace use cannot be investigated here due to lack of contextual information around the natural features (see Limitations) but cannot be ruled out. As the current sample was not matched for gender (72% female), it would be difficult to generalise findings without further confirmation. Given the gender-age interaction findings of Astell-Burt et al. (2014) and Bos et al. (2016), it may also have been useful to include interactional analyses. Given our much smaller sample size, however, this is unlikely to have produced reliable results.

In contrast to Cox et al. (2017), anxiety and depression symptoms were not found to have a moderating influence on the contact with natural features-wellbeing association. Although lower levels of wellbeing were associated with higher anxiety and depression symptoms, no differences in the contact with natural features association were seen. Although we must be cautious interpreting a null effect, clinically, in terms of intervention the absence of anxiety and depression moderation may be positive. It may demonstrate that anxiety and depression do not preclude people from reaping wellbeing benefits of nature. Participants were not recruited from clinical populations, however, so it may be that symptom severity was not high enough to demonstrate moderating effects.

This study also found associations between activities prior to the EMA and psychological wellbeing. Activities included social interaction, being outside, and exercise. Contact with natural features continuing to have significant associations with wellbeing even when these were accounted for, however, confirms the association remains over and above these predictors.

The fourth research question was whether subjective experience of COVID-19 influenced the contact with nature-wellbeing association. There were no associations between COVID-impact scores and the contact with nature-wellbeing association, suggesting lack of influence.

The final exploratory research question asked whether a difference would be found in scores for depression, anxiety, and COVID-impact following the EMA period and if this would be influenced by recruitment group. Findings indicated that the EMA period had a positive influence on both depression symptoms and COVID-impact scores. It also had some positive influence on anxiety symptoms, but to a lesser non-significant degree. Without inclusion of a control group, it would be difficult to draw definite conclusions from these findings. It does indicate, however, that there was some positive impact of undertaking the EMA period. Whether this related to EMA methods in general or more to the specific requests to notice nature or the way participants were feeling cannot as yet be ascertained. Recruitment group did not influence the pre and post EMA results, suggesting the two groups reacted similarly. This indicates that COVID-19 related restrictions did not play a part in the degree to which participants were affected by undertaking the EMA period.

**Limitations and Recommendations for Future Research**

A limitation of the current study was that information was not gathered about the context of natural feature contact. As previously demonstrated by Maes et al. (2021), there may be differences in the benefits reaped according to different natural contexts, i.e. woodland versus grassland. It may be that exposure to trees growing in urban pavements would have different associations with wellbeing than woodland trees, although they would be recorded as the same. Use of GPS information cross-referenced to responses could be used to assess this in future. Clinically, this could inform recommendations around optimal levels of nature.

Although there are many benefits to EMA smartphone protocols, some limitations were noted. Participants may be less likely to respond to notifications when truly immersed in nature, as commented on in the post-EMA questionnaire, thus potentially missing valuable nature experiences from the data. Asking participants to pay attention to and respond to their phones whilst in nature may reduce some of its benefits, especially if feeling connected is an important component. As suggested by Greenwood and Gatersleben (2016), the

distraction of using a phone may mean participants are not able to reap nature's restorative benefits, as they do not escape day-to-day life or engage with the fascination of it, essential components of Attention Restoration Theory (S. Kaplan, 1995).

EMAs themselves may also provide some form of intervention in a similar vein to self-monitoring in evidence-based treatments (J. S. Cohen et al., 2013), such as CBT. Being asked to actively notice what we are doing and how we are feeling can produce changes in our behaviour (Joyce Maas et al., 2013; Shiffman et al., 2008), although this reactivity cannot be seen in all EMA studies, being more likely when participants are actively trying to change their behaviour (Shiffman et al., 2008), which was not the case here. By including a wellbeing measure, EMAs may have acted similarly to mood-monitoring apps found to increase wellbeing and decrease anxiety and depression (Bakker & Rickard, 2018). Improvements in PHQ-8, GAD-7, and COVID-impact scores suggest this could be possible.

A further limitation was the omission of important demographic questions, such as ethnicity. Due to the location of most participants, it is unlikely that an ethnically diverse group were recruited, but there still may have been important missed differences. SES was not accurately accounted for, as the categorical Household Income measure could not be used due to its arbitrary nature and open ends. The dichotomous Income-level variable was thus computed but likely to have been a crude measure at best. An important extension could be to recruit participants from more diverse backgrounds, investigating whether differences occur in the nature-wellbeing association and informing intervention questions of what works for whom.

A bias may have been introduced by the recruitment processes. As a proportion of participants were recruited via social media and personal contacts of the researchers, it is possible this will have introduced some bias, as participants may have been more likely to come from similar backgrounds. It is likely that the longer-term assessment process will have reduced the potential for demand characteristic bias risked by participants knowing or knowing of the researchers. This cannot be ruled out as a possibility, however.

**Clinical Implications**

Natural feature contact was found to be positively associated with wellbeing over and above many other variables and individual characteristics. Levels of depression and anxiety symptoms were not associated with differences in this relationship. Although causality cannot be determined at this stage due to the cross-sectional design, findings suggest exposure to nature may be a useful recommendation for its association with wellbeing. Confirmation of the potential causal role of natural feature contact in this relationship is needed to establish whether they are worth including in interventions. Studies should also consider whether nature exposure is sufficient or if attention should be directed to it to increase feelings of being in contact.

The EMA design provided support for use of EMIs encompassing nature exposure, as participation in the study was associated with reduced symptoms of depression and anxiety. The possibility that this was related to wellbeing monitoring or being asked to notice natural features is as yet unclear and could be a useful focus of future studies.

The finding that anxiety and depression symptom levels were not associated with changes in the nature-wellbeing link is potentially clinically important. Lack of a clinical sample means it cannot be concluded that these populations would respond in the same way, but as a relatively broad spread of symptom levels was included it could tentatively be suggested that depression and anxiety do not appear to moderate the nature-wellbeing association. If this is confirmed with a clinical sample, it could mean inclusion of nature interventions as an avenue of further research informing alternative or adjunctive treatment options. If nature is found to increase wellbeing, this could add to positive interventions addressing underserved aspects of depression.

Relatively high response rates for the study (M=83.97%) indicates the design was feasible and relatively burden-less. This could be used to inform EMI designs, as the low-demand design could encourage compliance and reduce drop-out. It should be noted that

nine participants were excluded due to lower response rates, however, with these ranging from 9-44.19%, indicating some individual differences regarding compliance.

Gender was the only individual characteristic consistently associated with nature-wellbeing associations, with men showing stronger associations with more natural feature contact than women. This must be assessed with caution due to relatively low numbers of male participants. It is in line with previous findings using different outcomes, however. Along with previous findings, it may indicate that men reap more benefits from increased nature. Further experimental studies are needed to clarify this and inform tailored intervention.

## Conclusion

In conclusion, this study builds on evidence of a positive nature-wellbeing association using a longitudinal real-time EMA design whilst taking individual characteristics and likely confounders into account. It highlights the potential importance of both exposure to natural features and feeling in contact with nature for subjective psychological wellbeing. Although individual differences were not shown to have a consistent influence on the association, this may have been impacted by sampling and methodological issues and cannot yet be ruled out. It is also possible, however, that nature is a powerful component for wellbeing, holding its association over and above individual characteristics. Further experimental research is warranted to determine how nature based clinical interventions could be most effective. It is also important to bear in mind the preventative wellbeing potential of nature as it may be an important component to the population's mental health on a broader level, potentially helping negate some of the negative impacts of increasing urbanisation. In the meantime, the advocation of exposure to nature is encouraged for its association with increased wellbeing.

## References

Astell-Burt, T., Mitchell, R., & Hartig, T. (2014). The association between green space and mental health varies across the lifecourse. a longitudinal study. *Journal of Epidemiology and Community Health*, *68*(6), 578–583. https://doi.org/10.1136/jech-2013-203767

Bakker, D., & Rickard, N. (2018). Engagement in mobile phone app for self-monitoring of emotional wellbeing predicts changes in mental health: MoodPrism. *Journal of Affective Disorders*, *227*, 432–442. https://doi.org/10.1016/j.jad.2017.11.016

Bakolis, I., Hammoud, R., Smythe, M., Gibbons, J., Davidson, N., Tognin, S., & Mechelli, A. (2018). Urban Mind: Using Smartphone Technologies to Investigate the Impact of Nature on Mental Well-Being in Real Time. *BioScience*, *68*(2), 134–145. https://doi.org/10.1093/biosci/bix149

Bates, D., Maechler, M., Bolker, B., Walker, S., Haubo, R., Christensen, B., Singmann, H., Dai, B., Scheipl, F., & Grothendieck, G. (2015). Package 'lme4.' *Convergence*, *12*(1). https://cran.r-project.org/web/packages/lme4/

Bondy, B. (2002). Pathophysiology of depression and mechanisms of treatment. *Dialogues in Clinical Neuroscience*, *4*(1), 7–20. https://doi.org/10.31887/dcns.2002.4.1/bbondy

Bos, E. H., van der Meulen, L., Wichers, M., & Jeronimus, B. F. (2016). A primrose path? Moderating effects of age and gender in the association between green space and mental health. *International Journal of Environmental Research and Public Health*, *13*(5). https://doi.org/10.3390/ijerph13050492

Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, *97*, 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006

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. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(28), 8567–8572. https://doi.org/10.1073/pnas.1510459112

Britton, E., Kindermann, G., Domegan, C., & Carlin, C. (2018). Blue care: a systematic review of blue space interventions for health and wellbeing. *Health Promotion International*, 1–20. https://doi.org/10.1093/heapro/day103

Burnett, H., Olsen, J. R., Nicholls, N., & Mitchell, R. (2021). Change in time spent visiting and experiences of green space following restrictions on movement during the COVID-19 pandemic: A nationally representative cross-sectional study of UK adults. *BMJ Open*, *11*(3), 1–10. https://doi.org/10.1136/bmjopen-2020-044067

Capaldi A., C. A., Dopko L., R. L., & Zelenski, J. M. (2014). The relationship between nature connectedness and happiness: A meta-analysis. *Frontiers in Psychology*, *5*(AUG), 1–15. https://doi.org/10.3389/fpsyg.2014.00976

Chaves, C., Lopez-Gomez, I., Hervas, G., & Vazquez, C. (2019). The Integrative Positive Psychological Intervention for Depression (IPPI-D). *Journal of Contemporary Psychotherapy*, *49*(3), 177–185. https://doi.org/10.1007/s10879-018-9412-0

Chawla, L. (2015). Benefits of Nature Contact for Children. *Journal of Planning Literature*, *30*(4), 433–452. https://doi.org/10.1177/0885412215595441

Cohen-Cline, H., Turkheimer, E., & 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

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences*. Lawrence Erlbaum Associates.

Cohen, J. S., Edmunds, J. M., Brodman, D. M., Benjamin, C. L., & Kendall, P. C. (2013). Using Self-Monitoring: Implementation of Collaborative Empiricism in Cognitive-Behavioral Therapy. *Cognitive and Behavioral Practice*, *20*(4), 419–428. https://doi.org/10.1016/j.cbpra.2012.06.002

Cox, D. T. C., Shanahan, D. F., Hudson, H. L., Plummer, K. E., Siriwardena, G. M., Fuller, R. A., Anderson, K., Hancock, S., & Gaston, K. J. (2017). Doses of neighborhood nature: The benefits for mental health of living with nature. *BioScience*, *67*(2), 147–155.

https://doi.org/10.1093/biosci/biw173

Dadvand, P., Rivas, I., Basagaña, X., Alvarez-Pedrerol, M., Su, J., De Castro Pascual, M., Amato, F., Jerret, M., Querol, X., Sunyer, J., & Nieuwenhuijsen, M. J. (2015). The association between greenness and traffic-related air pollution at schools. *Science of the Total Environment*, *523*, 59–63. https://doi.org/10.1016/j.scitotenv.2015.03.103

Day, B. H. (2020). The Value of Greenspace Under Pandemic Lockdown. *Environmental and Resource Economics*, *76*(4), 1161–1185. https://doi.org/10.1007/s10640-020-00489-y

de Bell, S., Graham, H., Jarvis, S., & 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*(May), 118–127. https://doi.org/10.1016/j.landurbplan.2017.06.003

de Vries, L. P., Baselmans, B. M. L., & Bartels, M. (2021). Smartphone-Based Ecological Momentary Assessment of Well-Being: A Systematic Review and Recommendations for Future Studies. In *Journal of Happiness Studies* (Vol. 22, Issue 5). Springer Netherlands. https://doi.org/10.1007/s10902-020-00324-7

DESA, U. (2018). *World Urbanization Prospects: The 2018 Revision*.

Duckworth, A. L., Steen, T. A., & Seligman, M. E. P. (2005). Positive psychology in clinical practice. *Annual Review of Clinical Psychology*, *1*, 629–651. https://doi.org/10.1146/annurev.clinpsy.1.102803.144154

Dunn, B. D. (2012). Helping Depressed Clients Reconnect to Positive Emotion Experience: Current Insights and Future Directions. *Clinical Psychology and Psychotherapy*, *19*(4), 326–340. https://doi.org/10.1002/cpp.1799

Dzhambov, A. M., & Dimitrova, D. D. (2015). Green spaces and environmental noise perception. *Urban Forestry and Urban Greening*, *14*(4), 1000–1008. https://doi.org/10.1016/j.ufug.2015.09.006

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. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(11), 5188–5193. https://doi.org/10.1073/pnas.1807504116

Feng, X., & Astell-Burt, T. (2017). The relationship between neighbourhood green space and child mental wellbeing depends upon whom you ask: Multilevel evidence from 3083 children aged 12–13 years. *International Journal of Environmental Research and Public Health*, *14*(3). https://doi.org/10.3390/ijerph14030235

Friedman, S., Imrie, S., Fink, E., Gedikoglu, M., & Hughes, C. (2022). Understanding changes to children's connection to nature during the COVID-19 pandemic and implications for child well-being. *People and Nature*, *4*(1), 155–165. https://doi.org/10.1002/pan3.10270

Gao, J., Zheng, P., Jia, Y., Chen, H., Mao, Y., Chen, S., Wang, Y., Fu, H., & Dai, J. (2020). Mental health problems and social media exposure during COVID-19 outbreak. *PLoS ONE*, *15*(4), 1–10. https://doi.org/10.1371/journal.pone.0231924

Gascon, M., Mas, M. T., Martínez, D., Dadvand, P., Forns, J., Plasència, A., & 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

Gascon, M., Sánchez-benavides, G., Dadvand, P., & Martínez, D. (2018). Long-term exposure to residential green and blue spaces and anxiety and depression in adults : A cross-sectional study. *Environmental Research*, *162*(January), 231–239. https://doi.org/10.1016/j.envres.2018.01.012

Gascon, M., Zijlema, W., Vert, C., White, M. P., & Nieuwenhuijsen, M. J. (2017). Outdoor blue spaces, human health and well-being: A systematic review of quantitative studies. *International Journal of Hygiene and Environmental Health*, *220*(8), 1207–1221.

https://doi.org/10.1016/j.ijheh.2017.08.004

Greenwood, A., & Gatersleben, B. (2016). Let's go outside! Environmental restoration amongst adolescents and the impact of friends and phones. *Journal of Environmental Psychology*, *48*, 131–139. https://doi.org/10.1016/j.jenvp.2016.09.007

Gruber, J., Clark, L. A., Abramowitz, J. S., Aldao, A., Chung, T., Forbes, E. E., Nagayama Hall, G. C., Hinshaw, S. P., Hollon, S., Klein, D. N., Levenson, R. W., McKay, D., Mendle, J., Neblett, E. W., Olatunji, B. O., Prinstein, M. J., Rottenberg, J., Albano, A. M., Borelli, J. L., … Weinstock, L. M. (2021). Mental Health and Clinical Psychological Science in the Time of COVID-19: Challenges, Opportunities, and a Call to Action. *American Psychologist*, *76*(3), 409–426. https://doi.org/10.1037/amp0000707

Gründahl, M., Deckert, J., & Hein, G. (2020). Three Questions to Consider Before Applying Ecological Momentary Interventions (EMI) in Psychiatry. *Frontiers in Psychiatry*, *11*(April), 1–5. https://doi.org/10.3389/fpsyt.2020.00333

Helbich, M., de Beurs, D., Kwan, M. P., O'Connor, R. C., & Groenewegen, P. P. (2018). Natural environments and suicide mortality in the Netherlands: a cross-sectional, ecological study. *The Lancet Planetary Health*, *2*(3), e134–e139. https://doi.org/10.1016/S2542-5196(18)30033-0

Heron, K. E., & Smyth, J. M. (2010). Ecological Momentary Interventions: Incorporating Mobile Technology Into Psychosocial and Health Behavior Treatments. *British Journal of Health Psychology*, *15*(1), 1–39. https://doi.org/0.1348/135910709X466063

Hirabayashi, S., & Nowak, D. J. (2016). Comprehensive national database of tree effects on air quality and human health in the United States. *Environmental Pollution*, *215*(August), 48–57. https://doi.org/https://doi.org/10.1016/j.envpol.2016.04.068

Holmes, E. A., O'Connor, R. C., Perry, V. H., Tracey, I., Wessely, S., Arseneault, L., Ballard, C., Christensen, H., Cohen Silver, R., Everall, I., Ford, T., John, A., Kabir, T., King, K., Madan, I., Michie, S., Przybylski, A. K., Shafran, R., Sweeney, A., … Bullmore, E. (2020). Multidisciplinary research priorities for the COVID-19 pandemic: a call for action

for mental health science. *The Lancet Psychiatry*, *7*(6), 547–560. https://doi.org/10.1016/S2215-0366(20)30168-1

Houlden, V., Weich, S., de Albuquerque, J. P., Jarvis, S., & Rees, K. (2018). The relationship between greenspace and the mental wellbeing of adults: A systematic review. In *PLoS ONE* (Vol. 13, Issue 9). https://doi.org/10.1371/journal.pone.0203000

Huppert, F. A. (2009). Psychological Well-being: Evidence Regarding its Causes and Consequences. *Applied Psychology: Health and Well-Being*, *1*(2), 137–164. https://doi.org/10.1111/j.1758-0854.2009.01008.x

Hyde, A. L., Maher, J. P., & Elavsky, S. (2013). Enhancing our understanding of physical activity and wellbeing with a lifespan perspective. *International Journal of Wellbeing*, *3*(1), 98–115. https://doi.org/10.5502/ijw.v3i1.6

*ICD-10 Version:2016*. (n.d.). https://icd.who.int/browse10/2016/en#/F32

Jaso, B. A., Kraus, N. I., & Heller, A. S. (2021). Identification of careless responding in ecological momentary assessment research: From posthoc analyses to real-time data monitoring. *Psychological Methods*. https://doi.org/10.1037/met0000312

Jiang, B., Li, D., Larsen, L., & Sullivan, W. C. (2016). A Dose-Response Curve Describing the Relationship Between Urban Tree Cover Density and Self-Reported Stress Recovery. *Environment and Behavior*, *48*(4), 607–629. https://doi.org/10.1177/0013916514552321

Kaplan, S. (1995). The restorative benefits of nature: Toward an intergrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182.

Keniger, L. E., Gaston, K. J., Irvine, K. N., & Fuller, R. A. (2013). What are the benefits of interacting with nature? *International Journal of Environmental Research and Public Health*, *10*(3), 913–935. https://doi.org/10.3390/ijerph10030913

Kish, L. (1965). *Survey Sampling*. John Wiley & Sons.

Kobau, R., Seligman, M. E. P., Peterson, C., Diener, E., & Zack, M. M. (2011). Improving Uptake of Essential Services Mental Health Promotion in Public Health : Perspectives

and Strategies From Positive Psychology. *American Journal of Public Health*, *101*(8), 1–9. https://doi.org/10.2105/AJPH.2010.300083

Kroenke, K., & Spitzer, R. L. (2002). The PHQ-9 : A New Depression Measure. *Psychiatric Annals*, *32*(9), 509–515. https://doi.org/170553651

Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2001). The PHQ-9: Validity of a Brief Depression Severity Measure. *Journal of General Internal Medicine*, *16*(9), 606–613.

Kroenke, K., Strine, T. W., Spitzer, R. L., Williams, J. B. W., Berry, J. T., & Mokdad, A. H. (2009). The PHQ-8 as a measure of current depression in the general population. *Journal of Affective Disorders*, *114*(1–3), 163–173. https://doi.org/10.1016/j.jad.2008.06.026

Lansford, J. E. (2018). A Lifespan Perspective on Subjective Well-Being. In E. Diener, S. Oishi, & L. Tay (Eds.), *Handbook of well-being* (pp. 1–15). DEF Publishers. https://doi.org/nobascholar.com

Lehberger, M., Kleih, A. K., & Sparke, K. (2021). Self-reported well-being and the importance of green spaces – A comparison of garden owners and non-garden owners in times of COVID-19. *Landscape and Urban Planning*, *212*(April), 104108. https://doi.org/10.1016/j.landurbplan.2021.104108

Li, D., Menotti, T., Ding, Y., & Wells, N. M. (2021). Life course nature exposure and mental health outcomes: A systematic review and future directions. *International Journal of Environmental Research and Public Health*, *18*(10). https://doi.org/10.3390/ijerph18105146

Maas, J., Verheij, R. A., De Vries, S., Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health*, *63*(12), 967–973. https://doi.org/10.1136/jech.2008.079038

Maas, Joyce, Hietbrink, L., Rinck, M., & Keijsers, G. P. J. (2013). Changing automatic behavior through self-monitoring: Does overt change also imply implicit change?

*Journal of Behavior Therapy and Experimental Psychiatry*, *44*(3), 279–284. https://doi.org/10.1016/j.jbtep.2012.12.002

MacKerron, G., & Mourato, S. (2013). Happiness is greater in natural environments. *Global Environmental Change*, *23*(5), 992–1000. https://doi.org/10.1016/j.gloenvcha.2013.03.010

Maes, M. J. A., Pirani, M., Booth, E. R., Shen, C., Milligan, B., Jones, K. E., & Toledano, M. B. (2021). Benefit of woodland and other natural environments for adolescents' cognition and mental health. *Nature Sustainability*, *4*(10), 851–858. https://doi.org/10.1038/s41893-021-00751-1

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M. J., Lupp, G., Richardson, E. A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., & Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research*, *158*(June), 301–317. https://doi.org/10.1016/j.envres.2017.06.028

Marroquín, B., Vine, V., & Morgan, R. (2020). Mental health during the COVID-19 pandemic: Effects of stay-at-home policies, social distancing behavior, and social resources. *Psychiatry Research*, *293*(May), 113419. https://doi.org/10.1016/j.psychres.2020.113419

Masterton, W., Carver, H., Parkes, T., & Park, K. (2020). Greenspace interventions for mental health in clinical and non-clinical populations: What works, for whom, and in what circumstances? *Health and Place*, *64*(April), 102338. https://doi.org/10.1016/j.healthplace.2020.102338

McCormick, R. (2017). Does Access to Green Space Impact the Mental Well-being of Children: A Systematic Review. *Journal of Pediatric Nursing*, *37*, 3–7. https://doi.org/10.1016/j.pedn.2017.08.027

McEwan, K., Richardson, M., Brindley, P., Sheffield, D., Tait, C., Johnson, S., Sutch, H., &

Ferguson, F. J. (2019). Shmapped: development of an app to record and promote the well-being benefits of noticing urban nature. *Translational Behavioral Medicine*, 1–11. https://doi.org/10.1093/tbm/ibz027

McEwan, K., Richardson, M., Brindley, P., Sheffield, D., Tait, C., Johnson, S., Sutch, H., & Ferguson, F. J. (2020). Shmapped: Development of an app to record and promote the well-being benefits of noticing urban nature. *Translational Behavioral Medicine*, *10*(3), 723–733. https://doi.org/10.1093/tbm/ibz027

McMahan, E. A., & Estes, D. (2015). The effect of contact with natural environments on positive and negative affect: A meta-analysis. *Journal of Positive Psychology*, *10*(6), 507–519. https://doi.org/10.1080/17439760.2014.994224

Moberly, N. J., & Watkins, E. R. (2008). Ruminative Self-Focus and Negative Affect: An Experience Sampling Study. *Journal of Abnormal Psychology*, *117*(2), 314–323. https://doi.org/10.1037/0021-843X.117.2.314

Norwood, M. F., Lakhani, A., Fullagar, S., Maujean, A., Downes, M., Byrne, J., Stewart, A., Barber, B., & Kendall, E. (2019). A narrative and systematic review of the behavioural, cognitive and emotional effects of passive nature exposure on young people: Evidence for prescribing change. *Landscape and Urban Planning*, *189*(April), 71–79. https://doi.org/10.1016/j.landurbplan.2019.04.007

O'Connor, R. C., Wetherall, K., Cleare, S., McClelland, H., Melson, A. J., Niedzwiedz, C. L., O'Carroll, R. E., O'Connor, D. B., Platt, S., Scowcroft, E., Watson, B., Zortea, T., Ferguson, E., & Robb, K. A. (2021). Mental health and well-being during the COVID-19 pandemic: Longitudinal analyses of adults in the UK COVID-19 Mental Health & Wellbeing study. *British Journal of Psychiatry*, *218*(6), 326–333. https://doi.org/10.1192/bjp.2020.212

Office for National Statistics (Institution). (2021). *Average household income , UK: financial year 2020*. https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances

/incomeandwealth/bulletins/householddisposableincomeandinequality/financialyear2020

Oswald, T. K., Rumbold, A. R., Kedzior, S. G. E., & Moore, V. M. (2020). Psychological impacts of " screen time " and " green time " for children and adolescents : A systematic scoping review. *PLoS ONE*, *15*(9), 1–52. https://doi.org/10.1371/journal.pone.0237725

Owens, M., & Bunce, H. L. I. (2022). The Potential for Outdoor Nature-Based Interventions in the Treatment and Prevention of Depression. *Frontiers in Psychology*, *13*(March), 920. https://doi.org/10.3389/fpsyg.2022.740210

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*, *756*, 143984. https://doi.org/10.1016/j.scitotenv.2020.143984

Preuß, M., Nieuwenhuijsen, M., Marquez, S., Cirach, M., Grazuleviciene, R., Kruize, H., & Zijlema, W. (2019). Low childhood nature exposure is associated with worse mental health in adulthood. *International Journal of Environmental Research and Public Health*, *16*(10), 1809. https://doi.org/10.3390/ijerph16101809

Raanaas, R. K., Patil, G. G., & Hartig, T. (2012). Health benefits of a view of nature through the window: A quasi-experimental study of patients in a residential rehabilitation center. *Clinical Rehabilitation*, *26*(1), 21–32. https://doi.org/10.1177/0269215511412800

Repke, M. A., Berry, M. S., Conway, L. G., Metcalf, A., Hensen, M., & Phelan, C. (2018). How does nature exposure make people healthier ?: Evidence for the role of impulsivity and expanded space perception. *PLoS ONE*, *13*(8), e0202246.

Richardson, E. A., & Mitchell, R. (2010). Gender differences in relationships between urban green space and health in the United Kingdom. *Social Science and Medicine*, *71*(3), 568–575. https://doi.org/10.1016/j.socscimed.2010.04.015

Royal Society for the Protection of Birds. (2020). *Recovering Together: A report of public opinion on the role and importance of nature during and in our recovery from the*

*Coronavirus crisis in England*. https://doi.org/10.1097/anc.0000000000000819

Ryan, R., & Deci, E. (2001). On Happiness and Human Potentials: A Review of Research on Hedonic and Eudaimonic Well-Being. *Annual Review of Psychology*, *52*, 141–166. https://doi.org/10.1146/annurev.psych.52.1.141

Sandstrom, G. M., & Dunn, E. W. (2014). Social interactions and well-being: The surprising power of weak ties. *Personality and Social Psychology Bulletin*, *40*(7), 910–922. https://doi.org/10.1177/0146167214529799

Schueller, S. M., Aguilera, A., & Mohr, D. C. (2017). Ecological momentary interventions for depression and anxiety. *Depression and Anxiety*, *34*(6), 540–545. https://doi.org/10.1002/da.22649

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological Momentary Assessment. *Annual Review of Clinical Psychology*, *4*, 1–32. https://doi.org/10.1002/9781118384404.ch20

Slade, M. (2010). Mental illness and well-being : the central importance of positive psychology and recovery approaches. *BMC Health Services Research*, *10*(1), 26.

Spitzer, R. L., Kroenke, K., Williams, J. B. W., & Löwe, B. (2006). A brief measure for assessing generalized anxiety disorder: The GAD-7. *Archives of Internal Medicine*, *166*(10), 1092–1097. https://doi.org/10.1001/archinte.166.10.1092

Tennant, R., Hiller, L., Fishwick, R., Platt, S., Joseph, S., Weich, S., Parkinson, J., Secker, J., & Stewart-Brown, S. (2007). The Warwick-Edinburgh mental well-being scale (WEMWBS): Development and UK validation. *Health and Quality of Life Outcomes*, *5*, 1–13. https://doi.org/10.1186/1477-7525-5-63

The Mental Health Policy Group. (2015). *A Manifesto for Better Mental Health*. https://www.mind.org.uk/media-a/4404/a-manifesto-for-better-mental-health.pdf

Twohig-Bennett, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. *Environmental Research*, *166*(February), 628–637.

https://doi.org/10.1016/j.envres.2018.06.030

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*(3), 201–230. https://doi.org/10.1016/S0272-4944(05)80184-7

van den Berg, M. M., van Poppel, M., van Kamp, I., Ruijsbroek, A., Triguero-Mas, M., Gidlow, C., Nieuwenhuijsen, M. J., Gražulevičiene, R., van Mechelen, W., Kruize, H., & Maas, J. (2019). Do Physical Activity, Social Cohesion, and Loneliness Mediate the Association Between Time Spent Visiting Green Space and Mental Health? *Environment and Behavior*, *51*(2), 144–166. https://doi.org/10.1177/0013916517738563

Versluis, A., Verkuil, B., Spinhoven, P., Van Der Ploeg, M. M., & Brosschot, J. F. (2016). Changing mental health and positive psychological well-being using ecological momentary interventions: A systematic review and meta-analysis. *Journal of Medical Internet Research*, *18*(6). https://doi.org/10.2196/jmir.5642

Wheeler, B. W., White, M., Stahl-Timmins, W., & Depledge, M. H. (2012). Does living by the coast improve health and wellbeing. *Health and Place*, *18*(5), 1198–1201. https://doi.org/10.1016/j.healthplace.2012.06.015

Wilson, E. O. (1993). Biophilia and the conservation ethic. In S. R. Kellert & E. O. Wilson (Eds.), *The Biophilia Hypothesis* (pp. 31–41). Island Press.

World Health Organization. (2021). *Comprehensive Mental Health Action Plan 2013-2030*. https://www.who.int/publications/i/item/9789240031029

Yaremych, H. E., Preacher, K. J., & Hedeker, D. (2021). Centering Categorical Predictors in Multilevel Models: Best Practices and Interpretation. *Psychological Methods*. https://doi.org/10.1037/met0000434.supp

Zhang, Y., Mavoa, S., Zhao, J., Raphael, D., & Smith, M. (2020). The Association between Green Space and Adolescents ' Mental Well-Being : A Systematic Review. *International Journal of Environmental Research and Public Health*, *17*(18), 6640.

https://doi.org/10.3390/ijerph17186640

# Appendices

## Appendix A: University of Exeter Psychology Ethics Committee Approval

**CLES – Psychology**
Psychology
College of Life and Environmental Sciences
University of Exeter
Washington Singer Building
Perry Road
Exeter
EX4 4QG
Web: www.exeter.ac.uk

**CLES – Psychology Ethics Committee**

Dear Eva Nielsen

**Ethics application - eCLESPsy001488**
The benefits of nature on psychological well-being in a time of social distancing

Your project has been reviewed by the CLES – Psychology Ethics Committee and has received a Favourable with conditions opinion.

The Committee has made the following comments about your application:
**A few final changes required (no need to resubmit). - please remove Chris Dodds from Chair of Eth ics (Gail Seymour will suffice). - in the PIS, state that the researcher/university is not liable for any d amage to participants' phones associated with downloading the app, but that it has been developed re sponsibly and believed to be safe. - in the debrief for people who are screened out, state that t he measures are not clinically diagnostic as these feelings may emerge from time to time, but if suc**
- Please view your application at https://eethics.exeter.ac.uk/CLESPsy/ to see comments in full.
If you have received a Favourable with conditions, Provisional or unfavourable outcome you are required to re-submit for full review and/or confirm that committee comments have been addressed before you begin your research.

If you have any further queries, please contact your Ethics Officer.

Yours sincerely

Date: 13/09/2021

CLES – Psychology Ethics Committee

# Re: Ethics amendments (eCLESPsy001488 v2.1)

**JM**

Janbakhsh, Melika
Wed 08/07/2020 08:38

To:

- Nielsen, Eva;
- Dodds, Chris

Cc: Morgan, Celia

Dear Eva,

Thank you for your email and making the requested amendments. I checked your documents and now you can upload these on the ethics application system.

Good luck with your study and hope you'll get interesting results.

Best,
Melika

---

**From:** Nielsen, Eva <en290@exeter.ac.uk>
**Sent:** 08 July 2020 08:34
**To:** Janbakhsh, Melika <mj268@exeter.ac.uk>; Dodds, Chris <C.M.Dodds@exeter.ac.uk>
**Cc:** Morgan, Celia <Celia.Morgan@exeter.ac.uk>
**Subject:** Ethics amendments (eCLESPsy001488 v2.1)

Dear Melika and Chris,

As requested in my ethics application comments (ref. eCLESPsy001488 v2.1), please find attached my amended information sheet and debriefs. I've highlighted any changes. Please let me know if these should also be uploaded to the ethics application system. Thanks.

Kind regards,

Eva

## Appendix B: COVID-19 Qualtrics Survey Items

Start of Block: Covid-19 Questions

Q37 Are you currently having to self-isolate due to Covid-19 (coronavirus)

- Yes (1)
- No (2)

Q38 How much is Covid-19 currently affecting your life?

- Not at all (1)
- A little (2)
- A moderate amount (3)
- A lot (4)
- A great deal (5)

Q39 How anxious or worried do you currently feel about Covid-19?

- Not at all (1)
- A little (2)
- A moderate amount (3)
- A lot (4)
- A great deal (5)

Q40 How much is Covid-19 currently affecting your social life?

- Not at all (1)
- A little (2)
- A moderate amount (3)
- A lot (4)
- A great deal (5)

Q57 If you do so normally, are you currently able to attend school/work?

- Yes (1)
- Yes, but for less time than usual (2)
- No (4)

Q58 Are you currently able to see friends/family as you wish to?

- Yes, as normal (1)
- Yes, to a lesser extent or in different ways (2)
- No (3)

Q59 In your area, what level of Covid-19 related lockdown is currently in place?

- Full lockdown (4)
- Some easing of lockdown (5)
- Significant easing of lockdown (6)
- Little/no evidence of lockdown (7)

## Appendix C: Adapted Warwick-Edinburgh Mental Well-being Scale included in EMA

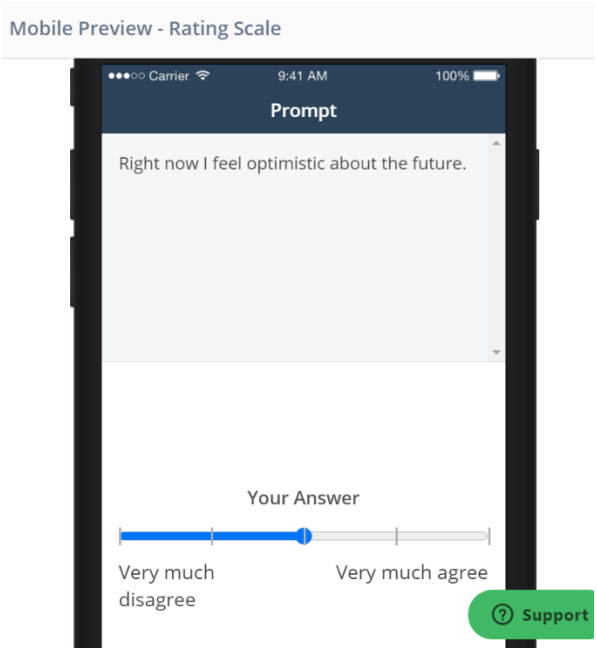
### Items

1. Right now I feel optimistic about the future.
2. Right now I feel useful.
3. Right now I feel relaxed.
4. Right now I feel interested in other people.
5. Right now I feel I have energy to spare.
6. Right now I deal with problems well.
7. Right now I think clearly.
8. Right now I feel good about myself.
9. Right now I feel close to other people.
10. Right now I feel confident.
11. Right now I am able to make up my own mind about things.
12. Right now I feel loved.
13. Right now I am interested in new things.
14. Right now I feel cheerful.

### Response Options and Associated Scoring

I very much disagree (score: 1)
I slightly disagree (score: 2)
Not sure (score: 3)
I slightly agree (score: 4)
I very much agree (score: 5)

### Presentation Preview



## Appendix D: Debrief Information Sheet

### Participant Debrief Sheet

Thank you for taking part in this study.

We hope the responses we have collected from you will help us to understand the complex interplay between nature and psychological wellbeing, especially in this time of social distancing.

If you are concerned about yours or a loved one's mental health and would like to seek further help, please see the below websites for support.

For information, help, and support for people who are depressed please visit **Mind** at https://www.mind.org.uk/

If you would like more information on general mental health support, please visit **SANE** at http://www.sane.org.uk/

For information on what you can do to help cope with mental health and useful information on mental health treatment from a UK perspective visit **Royal College of Psychiatrists** at https://www.rcpsych.ac.uk/

If you would like a summary of useful self-help approaches for depression please see the PDF from the Royal College of Psychiatrists: http://www.exeter.ac.uk/media/universityofexeter/schoolofpsychology/mooddisordercentre/documents/helpathand.pdf

To find the nearest cognitive behavioural therapists to where you live visit **British Association of Behavioural and Cognitive Psychotherapy (BABCP)** at https://www.babcp.com/Default.aspx

**Healthline** provides a very comprehensive overview of bipolar disorder as a critical starting point for individuals and/or their loved ones. For more information visit https://www.healthline.com/

The **Samaritans** provide a telephone support line for anyone struggling with their mental health. For help please visit https://www.samaritans.org/

**Young minds** provide mental health support for young people and parents. Please go to https://youngminds.org.uk/

**Rethink** is a national mental health charity: information, services & a strong voice for everyone affected by mental illness - challenging attitudes and changing lives. For more about them visit https://www.rethink.org/

Please remember you are entitled to withdraw your data from the study and can do this by contacting the main researcher Eva Nielsen at en290@exeter.ac.uk or Celia Morgan at Celia.Morgan@exeter.ac.uk. You can withdraw your data at any point, but we will not be able to

change the results to reflect this following publication of the findings (February 2021 at earliest). No identifiable information will be included in the write-up of the study.

Thank you again for your time and help on this project. If you have any concerns about the ethical conduct of the research please contact Dr Chris Dodds, Chair of the Psychology Research Ethics Committee on C.M.Dodds@exeter.ac.uk

## Appendix D: MLM Model3 Results: GAD-7

**Table 5.**

*Model3: Multi-level model fixed estimates for full model including GAD-7 as predictor*

| | Variable | Fixed Effect Estimate (Std.Error) | 95% Confidence Intervals |
|---|---|---|---|
| **Main Effects** | Intercept | 3.82 (0.12)*** | 3.59, 4.05 |
| | Total Natural Feature Contact | 0.07 (0.03)* | 0.01, 0.14 |
| | Income | 0.03 (0.12) | -0.19, 0.26 |
| | Age | 0.005 (0.005) | -0.003, 0.01 |
| | Gender | -0.21 (0.12) | -0.44, 0.02 |
| | GAD-7 (pre-EMA) | -0.05 (0.01)*** | -0.07, -0.03 |
| | Covid Impact (pre-EMA) | 0.06 (0.08) | -0.09, 0.21 |
| | Exercise since last measurement | 0.09 (0.03)*** | 0.04, 0.14 |
| | People since last measurement | 0.18 (0.03)*** | 0.11, 0.24 |
| | Outside since last measurement | 0.12 (0.02)*** | 0.07, 0.17 |
| | Between person: Average Natural Features | 0.06 (0.10) | -0.13, 0.25 |
| **Interactions** | Total Natural Feature Contact *Income | -0.002 (0.03) | -0.06, 0.06 |
| | Total Natural Feature Contact *Age | -0.003 (0.001)* | -0.005, -0.0006 |
| | Total Natural Feature Contact *Gender | 0.10 (0.03)** | 0.03, 0.16 |
| | Total Natural Feature Contact *GAD-7 (pre-EMA) | -0.005 (0.003)** | -0.01, 0.002 |
| | Total Natural Feature Contact *Covid Impact (pre-EMA) | 0.01 (0.02) | -0.03, 0.05 |
| | Total Natural Feature Contact *Exercise since last measurement | -0.003 (0.02) | -0.04, 0.04 |
| | Total Natural Feature Contact *People since last measurement | -0.05 (0.03) | -0.11, -0.0004 |
| | Total Natural Feature Contact *Outside since last measurement | 0.02 (0.02) | -0.02, 0.06 |
| | Total Natural Feature Contact *Average Natural Features | 0.009 (0.03) | -0.05, 0.06 |

*Note.* Significance at the $p < .001$ level indicated with **. Significance at the $p < .05$ indicated with *. Medium – large correlations indicated by bolded values.

## Appendix E: MLM Model4 Results: Felt Nature Contact

**Table 6.**

*Model4: Multi-level model fixed estimates for full model including Felt Nature Contact as a level-1 predictor (not Natural Feature Contact)*

| | Variable | Fixed Effect Estimate (Std.Error) | 95% Confidence Intervals |
|---|---|---|---|
| **Main Effects** | Intercept | 3.79 (0.11)*** | 3.59, 3.99 |
| | Felt Nature Contact | 0.19 (0.03)*** | 0.12, 0.25 |
| | Income | 0.09 (0.10) | -0.12, 0.28 |
| | Age | 0.004 (0.004) | -0.003, 0.01 |
| | Gender | -0.23 (0.10)* | -0.43, -0.04 |
| | PHQ-8 (pre-EMA) | -0.05 (0.01)*** | -0.07, -0.03 |
| | Covid Impact (pre-EMA) | 0.008 (0.07) | -0.12, 0.14 |
| | Exercise since last measurement | 0.04 (0.02) | -0.01, 0.09 |
| | People since last measurement | 0.17 (0.03)*** | 0.11, 0.23 |
| | Outside since last measurement | 0.07 (0.02)** | 0.02, 0.11 |
| | Between person: Average Natural Feature Contact | -0.03 (0.09) | -0.19, 0.14 |
| **Interactions** | Felt Nature Contact*Income | -0.04 (0.03) | -0.10, 0.02 |
| | Felt Nature Contact*Age | -0.001 (0.001) | -0.003, 0.001 |
| | Felt Nature Contact*Gender | 0.03 (0.03) | -0.03, 0.10 |
| | Felt Nature Contact *PHQ-8 (pre-EMA) | 0.004 (0.003) | -0.001, 0.01 |
| | Felt Nature Contact*Covid Impact (pre-EMA) | 0.02 (0.02) | -0.02, 0.06 |
| | Felt Nature Contact*Exercise since last measurement | -0.009 (0.01) | -0.04, 0.02 |
| | Felt Nature Contact*People since last measurement | -0.02 (0.02) | -0.06, 0.01 |
| | Felt Nature Contact*Outside since last measurement | 0.01 (0.02) | -0.02, 0.04 |
| | Felt Nature Contact*Average Natural Feature Contact | 0.02 (0.03) | -0.03, 0.07 |

*Note.* Significance at the p < .001 level indicated with **. Significance at the p < .05 indicated with *. Medium – large correlations indicated by bolded values.

## Appendix F: MLM Model5 Description & Results: Notification Number

To explore whether a difference over time could be seen within EMA data for the contact with natural features–wellbeing link, an exploratory MLM (Model5, see table 8 below) was performed using notification number as a measure of time. As notifications were presented in order, the time from the start of the EMA period increased alongside notification number, i.e., notification 1 represents the first time point, notification 21 was presented on day seven, and notification 43 on day 14. As Time (notification number) is a level-one predictor, this was included with Total Natural Feature Contact as a random effect. This illustrated a significant main effect of notification number ($B$ = 0.004, SE = 0.001, $p < .01$), suggesting the contact with natural features-wellbeing association became stronger over time, i.e. a stronger association can be seen for higher notification numbers and therefore further along in time.

**Table 7.**

*Model5: Multi-level model fixed estimates for full model including Notification Number as an additional Level-1 predictor.*

| | Variable | Fixed Effect Estimate (Std.Error) | 95% Confidence Intervals |
|---|---|---|---|
| **Main Effects** | Intercept | 3.80 (0.19)*** | 3.57, 4.03 |
| | Natural Feature Contact | 0.07 (0.03)* | 0.007, 0.14 |
| | Notification Number | 0.004 (0.001)** | 0.001, 0.006 |
| | Income | -0.001 (0.11) | -0.21, 0.22 |
| | Age | 0.006 (0.004) | -0.002, 0.01 |
| | Gender | -0.26 (0.12)* | -0.48, -0.04 |
| | PHQ-8 (pre-EMA) | -0.05 (0.01)*** | -0.07, -0.03 |
| | Covid Impact (pre-EMA) | 0.06 (0.08) | -0.09, 0.20 |
| | Exercise since last measurement | 0.10 (0.02)*** | 0.05, 0.15 |
| | People since last measurement | 0.18 (0.03)*** | 0.11, 0.24 |
| | Outside since last measurement | 0.11 (0.02)*** | 0.06, 0.15 |
| | Between person: Average Natural Feature Contact | 0.02 (0.10) | -0.17, 0.20 |

| | | | |
|---|---|---|---|
| **Interactions** | Total Natural Feature Contact *Income | -0.002 (0.03) | -0.07, 0.06 |
| | Total Natural Feature Contact *Age | -0.003 (0.001)* | -0.005, -0.0002 |
| | Total Natural Feature Contact *Gender | 0.10 (0.03)** | 0.03, 0.17 |
| | Total Natural Feature Contact *PHQ-8 (pre-EMA) | -0.005 (0.003) | -0.01, 0.001 |
| | Total Natural Feature Contact *Covid Impact (pre-EMA) | 0.01 (0.02) | -0.03, 0.06 |
| | Total Natural Feature Contact *Exercise since last measurement | -0.0004 (0.02) | -0.04, 0.04 |
| | Total Natural Feature Contact *People since last measurement | -0.05 (0.03) | -0.10, 0.002 |
| | Total Natural Feature Contact *Outside since last measurement | 0.007 (0.02) | -0.03, 0.05 |
| | Total Natural Feature Contact *Average Natural Feature Contact | -0.003 (0.03) | -0.06, 0.05 |

*Note.* Significance at the $p < .001$ level indicated with **. Significance at the $p < .05$ indicated with *. Medium – large correlations indicated by bolded values.

## Appendix G: PloS ONE Submission Guidance

Note: Where inconsistent with university guidance, university guidance was followed.

### Submission Guidelines

#### Style and Format

| | |
|---|---|
| File format | Manuscript files can be in the following formats: DOC, DOCX, or RTF. Microsoft Word documents should not be locked or protected.<br><br>LaTeX manuscripts must be submitted as PDFs. Read the LaTeX guidelines. |
| Length | Manuscripts can be any length. There are no restrictions on word count, number of figures, or amount of supporting information.<br><br>We encourage you to present and discuss your findings concisely. |
| Font | Use a standard font size and any standard font, except for the font named "Symbol". To add symbols to the manuscript, use the Insert → Symbol function in your word processor or paste in the appropriate Unicode character. |
| Headings | Limit manuscript sections and sub-sections to 3 heading levels. Make sure heading levels are clearly indicated in the manuscript text. |
| Layout and spacing | Manuscript text should be double-spaced.<br><br>Do not format text in multiple columns. |
| Page and line numbers | Include page numbers and line numbers in the manuscript file. Use continuous line numbers (do not restart the numbering on each page). |
| Footnotes | Footnotes are not permitted. If your manuscript contains footnotes, move the information into the main text or the reference list, depending on the content. |
| Language | Manuscripts must be submitted in English.<br><br>You may submit translations of the manuscript or abstract as supporting information. Read the supporting information guidelines. |

| | |
|---|---|
| Abbreviations | Define abbreviations upon first appearance in the text.<br><br>Do not use non-standard abbreviations unless they appear at least three times in the text.<br><br>Keep abbreviations to a minimum. |
| Reference style | PLOS uses “Vancouver” style, as outlined in the ICMJE sample references.<br><br>See reference formatting examples and additional instructions below. |
| Equations | We recommend using MathType for display and inline equations, as it will provide the most reliable outcome. If this is not possible, Equation Editor or Microsoft's Insert→Equation function is acceptable.<br><br>Avoid using MathType, Equation Editor, or the Insert→Equation function to insert single variables (e.g., “$a^2 + b^2 = c^2$”), Greek or other symbols (e.g., β, Δ, or ′ [prime]), or mathematical operators (e.g., x, ≥, or ±) in running text. Wherever possible, insert single symbols as normal text with the correct Unicode (hex) values.<br><br>Do not use MathType, Equation Editor, or the Insert→Equation function for only a portion of an equation. Rather, ensure that the entire equation is included. Equations should not contain a mix of different equation tools. Avoid “hybrid” inline or display equations, in which part is text and part is MathType, or part is MathType and part is Equation Editor. |

**Copyediting manuscripts**

Prior to submission, authors who believe their manuscripts would benefit from professional editing are encouraged to use language-editing and copyediting services. Obtaining this service is the responsibility of the author, and should be done before initial submission. These services can be found on the web using search terms like “scientific editing service” or “manuscript editing service.”

## Manuscript Organization

Manuscripts should be organized as follows. Instructions for each element appear below the list.

| | |
|---|---|
| **Beginning section** | *The following elements are required, in order:*<br>• Title page: List title, authors, and affiliations as first page of the manuscript<br>• Abstract<br>• Introduction |
| **Middle section** | *The following elements can be renamed as needed and presented in any order:*<br>• Materials and Methods<br>• Results<br>• Discussion<br>• Conclusions (optional) |
| **Ending section** | *The following elements are required, in order:*<br>• Acknowledgments<br>• References<br>• Supporting information captions (if applicable) |
| **Other elements** | • Figure captions are inserted immediately after the first paragraph in which the figure is cited. Figure files are uploaded separately.<br>• Tables are inserted immediately after the first paragraph in which they are cited.<br>• Supporting information files are uploaded separately. |

**Viewing Figures and Supporting Information in the compiled submission PDF**
The compiled submission PDF includes low-resolution preview images of the figures after the reference list. The function of these previews is to allow you to download the entire submission as quickly as possible. Click the link at the top of each preview page to download a high-resolution version of each figure. Links to download Supporting Information files are also available after the reference list.

## Parts of a Submission

### Title

Include a full title and a short title for the manuscript.

| Title | Length | Guidelines | Examples |
|---|---|---|---|
| **Full title** | 250 characters | Specific, descriptive, concise, and comprehensible to readers outside the field | Impact of cigarette smoke exposure on innate immunity: A *Caenorhabditis elegans* model<br><br>Solar drinking water disinfection (SODIS) to reduce childhood diarrhoea in rural Bolivia: A cluster-randomized, controlled trial |
| **Short title** | 100 characters | State the topic of the study | Cigarette smoke exposure and innate immunity<br><br>SODIS and childhood diarrhoea |

Titles should be written in sentence case (only the first word of the text, proper nouns, and genus names are capitalized). Avoid specialist abbreviations if possible. For clinical trials, systematic reviews, or meta-analyses, the subtitle should include the study design.

### Author list

**Authorship requirements**

All authors must meet the criteria for authorship as outlined in the authorship policy. Those who contributed to the work but do not meet the criteria for authorship can be mentioned in the Acknowledgments. Read more about Acknowledgments.

The corresponding author must provide an ORCID iD at the time of submission by entering it in the user profile in the submission system. Read more about ORCID.

### *Author names and affiliations*

Enter author names on the title page of the manuscript and in the online submission system.

On the title page, write author names in the following order:

- First name (or initials, if used)
- Middle name (or initials, if used)
- Last name (surname, family name)

Each author on the list must have an affiliation. The affiliation includes department, university, or organizational affiliation and its location, including city, state/province (if applicable), and country. Authors have the option to include a current address in addition to the address of their affiliation at the time of the study. The current address should be listed in the byline and clearly labeled "current address." At a minimum, the address must include the author's current institution, city, and country.

If an author has multiple affiliations, enter all affiliations on the title page only. In the submission system, enter only the preferred or primary affiliation. Author affiliations will be listed in the typeset PDF article in the same order that authors are listed in the submission.

Author names will be published exactly as they appear in the manuscript file. Please double-check the information carefully to make sure it is correct.

### *Corresponding author*

The submitting author is automatically designated as the corresponding author in the submission system. The corresponding author is the primary contact for the journal office and the only author able to view or change the manuscript while it is under editorial consideration.

The corresponding author role may be transferred to another coauthor. However, note that transferring the corresponding author role also transfers access to the manuscript. (To designate a new corresponding author while the manuscript is still under consideration, watch the video tutorial below.)

Only one corresponding author can be designated in the submission system, but this does not restrict the number of corresponding authors that may be listed on the article in the event of publication. Whoever is designated as a corresponding author on the title page of the manuscript file will be listed as such upon publication. Include an email address for each corresponding author listed on the title page of the manuscript.

### *Consortia and group authorship*

If a manuscript is submitted on behalf of a consortium or group, include its name in the manuscript byline. Do not add it to the author list in the submission system. You may include the full list of members in the Acknowledgments or in a supporting information file.

PubMed only indexes individual consortium or group author members listed in the article byline. If included, these individuals must qualify for authorship

## Author contributions

Provide at minimum one contribution for each author in the submission system. Use the CRediT taxonomy to describe each contribution. Read the policy and the full list of roles.

Contributions will be published with the final article, and they should accurately reflect contributions to the work. The submitting author is responsible for completing this information at submission, and we expect that all authors will have reviewed, discussed, and agreed to their individual contributions ahead of this time.

*PLOS ONE* will contact all authors by email at submission to ensure that they are aware of the submission.

## Title page

The title, authors, and affiliations should all be included on a title page as the first page of the manuscript file.

 Download our sample title, author list, and affiliations page (PDF)

## Abstract

The Abstract comes after the title page in the manuscript file. The abstract text is also entered in a separate field in the submission system.

The Abstract should:

- Describe the main objective(s) of the study
- Explain how the study was done, including any model organisms used, without methodological detail
- Summarize the most important results and their significance

- Not exceed 300 words

Abstracts should not include:

- Citations
- Abbreviations, if possible

## Introduction

The introduction should:

- Provide background that puts the manuscript into context and allows readers outside the field to understand the purpose and significance of the study
- Define the problem addressed and why it is important
- Include a brief review of the key literature
- Note any relevant controversies or disagreements in the field
- Conclude with a brief statement of the overall aim of the work and a comment about whether that aim was achieved

## Materials and Methods

The Materials and Methods section should provide enough detail to allow suitably skilled investigators to fully replicate your study. Specific information and/or protocols for new methods should be included in detail. If materials, methods, and protocols are well established, authors may cite articles where those protocols are described in detail, but the submission should include sufficient information to be understood independent of these references.

### *Supporting reproducibility with protocols*

To enhance the reproducibility of your results, we recommend and encourage you to make your protocols public. There are several options:

#### Protocols associated with Research Articles

Protocol documents may be uploaded as Supporting Information or linked from the Methods section of the article. For laboratory protocols, we recommend protocols.io. Include the DOI link in the Methods section of your manuscript using the following format: http://dx.doi.org/10.17504/protocols.io.[PROTOCOL DOI].

This allows editors and reviewers to consult the detailed step-by-step protocol when evaluating your manuscript. You can choose to keep the protocol private on the protocols.io platform until your article is published—at which time it will be published automatically.

### Protocols published in their own right

*PLOS ONE* offers two options for publishing stand-alone protocol articles: Lab Protocols that describe reusable methodologies and Study Protocols that describe detailed plans and proposals for research projects. Specific guidelines apply to the submission of Lab Protocol and Study Protocol manuscripts. Read the detailed instructions for submitting Lab Protocols and Study Protocols.

### Results, Discussion, Conclusions

These sections may all be separate, or may be combined to create a mixed Results/Discussion section (commonly labeled "Results and Discussion") or a mixed Discussion/Conclusions section (commonly labeled "Discussion"). These sections may be further divided into subsections, each with a concise subheading, as appropriate. These sections have no word limit, but the language should be clear and concise.

Together, these sections should describe the results of the experiments, the interpretation of these results, and the conclusions that can be drawn.

Authors should explain how the results relate to the hypothesis presented as the basis of the study and provide a succinct explanation of the implications of the findings, particularly in relation to previous related studies and potential future directions for research.

*PLOS ONE* editorial decisions do not rely on perceived significance or impact, so authors should avoid overstating their conclusions. See the *PLOS ONE* Criteria for Publication for more information.

### Acknowledgments

Those who contributed to the work but do not meet our authorship criteria should be listed in the Acknowledgments with a description of the contribution.

Authors are responsible for ensuring that anyone named in the Acknowledgments agrees to be named.

PLOS journals publicly acknowledge the indispensable efforts of our editors and reviewers on an annual basis. To ensure equitable recognition and avoid any appearance of partiality, do not include editors or peer reviewers—named or unnamed—in the Acknowledgments.

Do not include funding sources in the Acknowledgments or anywhere else in the manuscript file. Funding information should only be entered in the financial disclosure section of the submission system.

## References

Any and all available works can be cited in the reference list. Acceptable sources include:

- Published or accepted manuscripts
- Manuscripts on preprint servers, providing the manuscript has a citable DOI or arXiv URL.

Do not cite the following sources in the reference list:

- Unavailable and unpublished work, including manuscripts that have been submitted but not yet accepted (e.g., "unpublished work," "data not shown"). Instead, include those data as supplementary material or deposit the data in a publicly available database.
- Personal communications (these should be supported by a letter from the relevant authors but not included in the reference list)
- Submitted research should not rely upon retracted research. You should avoid citing retracted articles unless you need to discuss retracted work to provide historical context for your submitted research. If it is necessary to discuss retracted work, state the article's retracted status in your article's text and reference list.

Ensure that your reference list includes full and current bibliography details for every cited work at the time of your article's submission (and publication, if accepted). If cited work is corrected, retracted, or marked with an expression of concern before your article is published, and if you feel it is appropriate to cite the work even in light of the post-publication notice, include in your manuscript citations and full references for both the affected article and the post-publication notice. Email the journal office if you have questions.

References are listed at the end of the manuscript and numbered in the order that they appear in the text. In the text, cite the reference number in square brackets (e.g., "We used the techniques developed by our colleagues [19] to analyze the data"). PLOS uses the numbered citation (citation-sequence) method and first six authors, et al.

Do not include citations in abstracts.

Make sure the parts of the manuscript are in the correct order *before* ordering the citations.

**Formatting references**

Because all references will be linked electronically as much as possible to the papers they cite, proper formatting of references is crucial.

PLOS uses the reference style outlined by the International Committee of Medical Journal Editors (ICMJE), also referred to as the "Vancouver" style. Example formats are listed below. Additional examples are in the ICMJE sample references.

A reference management tool, EndNote, offers a current style file that can assist you with the formatting of your references. If you have problems with any reference management program, please contact the source company's technical support.

Journal name abbreviations should be those found in the National Center for Biotechnology Information (NCBI) databases.

## Supporting information

Authors can submit essential supporting files and multimedia files along with their manuscripts. All supporting information will be subject to peer review. All file types can be submitted, but files must be smaller than 20 MB in size.

Authors may use almost any description as the item name for a supporting information file as long as it contains an "S" and number. For example, "S1 Appendix" and "S2 Appendix," "S1 Table" and "S2 Table," and so forth.

Supporting information files are published exactly as provided, and are not copyedited.

### *Supporting information captions*

List supporting information captions at the end of the manuscript file. Do not submit captions in a separate file.

The file number and name are required in a caption, and we highly recommend including a one-line title as well. You may also include a legend in your caption, but it is not required.

#### Example caption

**S1 Text. Title is strongly recommended.** Legend is optional.

### *In-text citations*

We recommend that you cite supporting information in the manuscript text, but this is not a requirement. If you cite supporting information in the text, citations do not need to be in numerical order.

## Figures and tables

### *Figures*

Do not include figures in the main manuscript file. Each figure must be prepared and submitted as an individual file.

Cite figures in ascending numeric order at first appearance in the manuscript file.

### *Figure captions*

Figure captions must be inserted in the text of the manuscript, immediately following the paragraph in which the figure is first cited (read order). Do not include captions as part of the figure files themselves or submit them in a separate document.

At a minimum, include the following in your figure captions:

- A figure label with Arabic numerals, and "Figure" abbreviated to "Fig" (e.g. Fig 1, Fig 2, Fig 3, etc). Match the label of your figure with the name of the file uploaded at submission (e.g. a figure citation of "Fig 1" must refer to a figure file named "Fig1.tif").
- A concise, descriptive title

The caption may also include a legend as needed.

### *Tables*

Cite tables in ascending numeric order upon first appearance in the manuscript file.

Place each table in your manuscript file directly after the paragraph in which it is first cited (read order). Do not submit your tables in separate files.

Tables require a label (e.g., "Table 1") and brief descriptive title to be placed above the table. Place legends, footnotes, and other text below the table.

## Statistical reporting

Manuscripts submitted to *PLOS ONE* are expected to report statistical methods in sufficient detail for others to replicate the analysis performed. Ensure that results are rigorously reported in accordance with community standards and that statistical methods employed are appropriate for the study design.

### *Reporting of statistical methods*

In the methods, include a section on statistical analysis that reports a detailed description of the statistical methods. In this section:

- List the name and version of any software package used, alongside any relevant references
- Describe technical details or procedures required to reproduce the analysis
- Provide the repository identifier for any code used in the analysis (See our code-sharing policy.)

Statistical reporting guidelines:

- Identify research design and independent variables as being between- or within-subjects
- For pre-processed data:
    - Describe any analysis carried out to confirm the data meets the assumptions of the analysis performed (e.g. linearity, co-linearity, normality of the distribution).
    - If data were transformed include this information, with a reason for doing so and a description of the transformation performed
- Provide details of how outliers were treated and your analysis, both with the full dataset and with the outliers removed
- If relevant, describe how missing/excluded data were handled
- Define the threshold for significance (alpha)
- If appropriate, provide sample sizes, along with a description of how they were determined. If a sample size calculation was performed, specify the inputs for power, effect size and alpha. Where relevant, report the number of independent replications for each experiment.
- For analyses of variance (ANOVAs), detail any post hoc tests that were performed
- Include details of any corrections applied to account for multiple comparisons. If corrections were not applied, include a justification for not doing so
- Describe all options for statistical procedures. For example, if t-tests were performed, state whether these were one- or two-tailed. Include details of the type of t-test conducted (e.g. one sample, within-/between-subjects).
- For step-wise multiple regression analyses:
    - Report the alpha level used

- Discuss whether the variables were assessed for collinearity and interaction
- Describe the variable selection process by which the final model was developed (e.g., forward-stepwise; best subset). See SAMPL guidelines.

- For Bayesian analysis explain the choice of prior trial probabilities and how they were selected. Markov chain Monte Carlo settings should be reported.

### *Reporting of statistical results*

Results must be rigorously and appropriately reported, in keeping with community standards.

- **Units of measurement.** Clearly define measurement units in all tables and figures.
- **Properties of distribution.** It should be clear from the text which measures of variance (standard deviation, standard error of the mean, confidence intervals) and central tendency (mean, median) are being presented.
- **Regression analyses.** Include the full results of any regression analysis performed as a supplementary file. Include all estimated regression coefficients, their standard error, p-values, and confidence intervals, as well as the measures of goodness of fit.
- **Reporting parameters.** Test statistics (F/t/r) and associated degrees of freedom should be provided. Effect sizes and confidence intervals should be reported where appropriate. If percentages are provided, the numerator and denominator should also be given.
- **P-values.** Report exact p-values for all values greater than or equal to 0.001. P-values less than 0.001 may be expressed as $p < 0.001$, or as exponentials in studies of genetic associations.
- **Displaying data in plots.** Format plots so that they accurately depict the sample distribution. 3D effects in plots can bias and hinder interpretation of values, so avoid them in cases where regular plots are sufficient to display the data.
- **Open data.** As explained in PLOS's Data Policy, be sure to make individual data points, underlying graphs and summary statistics available at the time of publication. Data can be deposited in a repository or included within the Supporting Information files.