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Associations of reported access to public green space, physical activity and subjective wellbeing during and after the COVID-19 pandemic

Wouter Poortinga [a,b,*], Jaiden Denney [c], Kirsty Marie Kelly [b], Rebecca Oates [b], Rhiannon Phillips [d], Helen Oliver [d], Britt Hallingberg [d]

[a] Welsh School of Architecture, Cardiff University, Cardiff, Wales, UK
[b] School of Psychology, Cardiff University, Cardiff, Wales, UK
[c] School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, England, UK
[d] Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, Wales, UK

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ABSTRACT

Access to green space and physical activity have both been shown to be associated with individuals' subjective wellbeing. The present study explored the role of physical activity in the association between reported access to public green space and subjective wellbeing at two distinct timepoints during (12 months after the beginning of) and after (24 months after the beginning of) the COVID-19 pandemic. This study made use of the longitudinal COPE dataset involving a series of online surveys administered to a cohort throughout the pandemic. A series of linear regression models revealed small but significant associations between reported access to public green space on the one hand and physical activity and subjective wellbeing on the other. The analyses further showed that physical activity partly mediates the relationship between reported access to public green space and subjective wellbeing at both the 12-month and 24-month timepoints. Physical activity and subjective wellbeing were higher at the 24-month than at the 12-month timepoint, but reported access to public green space did not play a role in these changes. Evidence was found that the increase in subjective wellbeing from 12 to 24 months can partly be explained by a change in physical activity.

1. Introduction

1.1. Background

The coronavirus disease (COVID-19) pandemic of 2020–22 resulted in unprecedented lifestyle and economic disruption worldwide, the aftershocks of which are likely to be felt for years. The impact of government-imposed restrictions, the death of loved ones, and changes in social connection and employment during the pandemic has had far reaching psychological and physical health consequences (Xiong et al., 2020). People used a range of coping strategies to deal with the changes that the COVID-19 pandemic bought to daily life (Ogueji et al., 2021). Many saw this as an opportunity for relaxation and personal development (Bell et al., 2021), or used the extra time to increase exercise or home cooking (Ogueji et al., 2021). However, others deployed coping mechanisms that negatively impacted their health behaviours, such as increased alcohol use and adopting less healthy dietary behaviours (Bell et al., 2021). During the early stages of the pandemic, when varying levels of physical distancing restrictions were in place, individuals spent considerably more time outdoors, using it as a medium for meeting up with friends and family and to reduce risk of infection (Jewett et al., 2021). Outdoor spaces were one of the few places that people could use for physical activity, relaxation and socialising at the height of the restrictions, and as such acted as a lifeline for many.

Consistent with an extensive pre-pandemic literature (Twohig-Bennett & Jones, 2018; Van den Berg et al., 2019), a robust body of work has demonstrated how access to public green space was associated with physical health and wellbeing during the COVID-19 restrictions (Vos et al., 2022). Research shows that both public and private green space were important (Lehberger & Sparke, 2023; Nigg et al., 2023), and notably that public green space may have partly compensated for the lack of having a private garden (Poortinga et al., 2021). Proximity of public green space appears to have acted as a buffer to maintain favourable health and quality of life during times of great

* Corresponding author. Welsh School of Architecture, Cardiff University, Cardiff, Wales, UK.
E-mail addresses: PoortingaW@cardiff.ac.uk (W. Poortinga), J.J.A.K.Denney@lboro.ac.uk (J. Denney), kirsty@walkntalktherapy.com (K.M. Kelly), OatesRK@cardiff.ac.uk (R. Oates), RPhillips2@cardiffmet.ac.uk (R. Phillips), HOliver@cardiffmet.ac.uk (H. Oliver), BHallingberg@cardiffmet.ac.uk (B. Hallingberg).

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distress (Xie et al., 2020). Already before the pandemic, it was shown that nature can help to reduce stress that people experience in urban areas (Houlden et al., 2018), and may be particularly important for mental wellbeing in periods with stressful life events (Marselle et al., 2019).

While the benefits of green space for mental wellbeing has been widely evidenced, the pathways underlying this relationship have received less attention (Shanahan et al., 2016), in particular during the pandemic. There are a number of potential pathways that link green space to health (Hartig et al., 2014). Markevych et al. (2017) organised these pathways according to three potential health functions of green space of reducing harm (e.g., reducing exposure to air pollution, noise and heat), restoring capacities (e.g., stress recovery and attention restoration), and building capacities (e.g., encouraging physical activity and social interactions). That is, spending time in nature and/or green space may be beneficial for people's health and wellbeing through reduced exposure to harmful road traffic noise and pollutants (Bloemsma et al., 2022); it may be beneficial for people's health and wellbeing by reducing exposure to social and environmental stressors and thus providing opportunities for recovery and restoration (Cox et al., 2017); and it may be beneficial for people's health and wellbeing because it provides opportunities for health-enhancing activities, such as exercise and socialising (Jennings & Bamkole, 2019).

In this paper, we focus on the physical activity pathway that may have mediated the association between access to public green space and subjective wellbeing during the COVID-19 pandemic. Spending time in nature offered time away from the pressures of home schooling and working during the COVID-19 pandemic (Pouso et al., 2021), and has as such been described as a nature-based coping mechanism (Berdejo-Espinola et al., 2021). Frühauf et al. (2020) purported that allowing green exercise for stress management and physical health was a "basic human need", especially during lockdowns. Access to, and use of, public green spaces during periods of lockdown were shown to decrease feelings of isolation (Dawwas & Dyson, 2021) and appear to have been protective against adverse mental health and depression symptoms (Soga et al., 2020). It is possible that closer proximity to public green space has mitigated against the pressures of lockdowns possibly due to increased opportunity to engage in physical activity (Slater et al., 2020).

Regular physical activity has long been understood to provide mental and physical health benefits across all age groups, in terms of improving mood and physical condition (Buecker et al., 2021). The World Health Organisation (WHO) recommends a minimum of 150 min of moderate/vigorous physical activity per week in order to attain the associated health benefits (Piercy et al., 2018). The benefits of engaging in regular physical activity are widely understood in terms of general health and wellbeing but may extend to being protective against severe disease. Da Silveira et al. (2020) show that physical activity is associated with a heightened COVID-19 immune response. Furthermore, physical activity is known to reduce the risk of obesity, which represents a risk-factor for severe COVID-19 disease (Luzi & Radaelli, 2020).

'Green exercise', such as walking or running in green space, is demonstrated to significantly improve physical and mental health above the same activity in urban settings (Barton et al., 2012). Rogerson et al. (2016) highlighted how spending time engaging in physical activity or exercise outdoors can improve attentional control, as compared to indoor activity. Green exercise is demonstrated to significantly improve physical and mental health above the same activity in urban settings (Barton et al., 2012; Bowler et al., 2010), and these benefits may be gained from any size and type of green space, from small urban parks to vast wilderness (Pretty et al., 2017). Further evidence suggests that visiting tree dense environments may increase the human immune function (Tsao et al., 2018). Roviello et al. (2021) suggest that exercise performed in green spaces is particularly protective of infectious disease due to the combined benefits of physical exercise and immunostimulatory effect provided by biogenic volatile organic components emitted by trees, in addition to the wellbeing benefits associated with spending time among trees. The restorative effects of spending time in nature are known to alleviate stress and anxiety, in turn lowering cortisol levels which helps strengthen the immune system (Jones et al., 2021).

Travel distance has been shown to be the main predictor of visits to green space (Zhang et al., 2021), with living closer to public green space being associated with greater likelihood of exercise (James et al., 2015; Kondo et al., 2018). There is a direct association between proximity to urban green spaces and increased physical activity across all age groups (Jennings & Bamkole, 2019), and evidence that living closer to green spaces is more strongly associated with exercise than living near sports centres (Kaczynski & Henderson, 2007). An eight-country study confirmed that perceived proximity to a park was positively associated with a range of objectively measured exercise outcomes (Schipperijn et al., 2017).

In line with the pre-pandemic literature, proximity to green spaces has been found to be associated with more frequent physical activity during the COVID-19 pandemic (Nicklett et al., 2024). There is evidence that more people have been spending time in nature and green space since the COVID-19 pandemic (Geng et al., 2020). During the early stages of the pandemic individuals may have adapted to lockdown conditions, with physical activity levels reported to have increased after the first week of restrictions in Spain (López-Bueno et al., 2020). Venter et al. (2021) reported that Norwegians sustained increased physical activity from the five weeks of comprehensive lockdown at the start of the pandemic until the summer vacation period in June/July when they dropped back to baseline levels. The greatest increases were found in urban green spaces as well as in forests and protected areas. Other research suggests that physical activity dropped during the COVID-19 pandemic. A recent systematic review found increases in sedentary behaviour and decreases in physical activity during periods of nationwide lockdowns (Stockwell et al., 2021). A Canadian study found that during the pandemic already inactive participants became less active, while active participants increased their physical activity levels (Lesser & Nienhuis, 2020). Most of the studies focusing on physical activity levels during the pandemic typically centred upon the first national lockdowns and subsequent months (Clemente-Suárez et al., 2022), with limited research exploring the effects of the pandemic on physical activity over time. Research by Wunsch et al. (2022) shows that physical activity levels dropped in early stages of the pandemic but then increased again after restrictions were lifted (Wunsch et al., 2022).

1.2. Aim of the study

The aim of the present study is to explore the associations between physical activity and reported access to green spaces and subjective well-being at two distinct timepoints during and after the COVID-19 pandemic: in March/April 2021, when physical distancing restrictions had been in place to varying extents for a period of 12 months, and a year later in March/April 2022, when all physical distancing restrictions had been removed across the UK (Senedd Research, 2022, UK Government, 2022). In particular, it aims to determine whether physical activity acts as a mediator between reported access to public green space and subjective wellbeing. While the benefits of green space for physical activity and subjective wellbeing have been widely evidenced, the pathways underlying this relationship have received less attention (Shanahan et al., 2016). Furthermore, there is limited evidence in regards of the relationships and pathways during and after the COVID-19 pandemic. While access to green space has been shown to be important for physical activity and subjective wellbeing both during and outside the pandemic, as shown in the literature review above (e.g., Kondo et al., 2018; Nicklett et al., 2024; Poortinga et al., 2021; Twohig-Bennett & Jones, 2018), its role at different periods has not been directly compared. Here, it is expected that access to green space was more important for physical activity and wellbeing when COVID-19 restrictions were in place as opportunities for other types of physical activity such as active travel, exercise indoors, organised group activities and/or or physical activity at a place of work or study would have been limited during this time, potentially amplifying the association between access to green space and physical activity. The research will further compare levels of physical activity both during and after the COVID-19 pandemic, with an expectation that overall levels of physical activity and subjective wellbeing were higher when restrictions were not in place (cf., Stockwell et al., 2021).

The specific objectives of the study are to examine:

Objective 1: whether reported access to public green space is associated with physical activity at 12 and 24 months after the beginning of the COVID-19 pandemic.

Objective 2: a) whether reported access to public green space is associated with subjective wellbeing at 12 and 24 months; and b) whether and to what extent physical activity mediates the association between reported access to public green space and subjective wellbeing.

Objective 3: whether reported access to public green space is associated with changes in physical activity from 12 to 24 months after the beginning of the COVID-19 pandemic.

Objective 4: a) whether access to public green space is associated with changes in subjective wellbeing, and b) whether changes in physical activity can explain changes in subjective wellbeing between 12 and 24 months after the beginning of the COVID-19 pandemic.

2. Methods

2.1. The COVID-19 public experiences (COPE) survey

This study makes use of the COVID-19 Public Experiences (COPE) data, a prospective longitudinal survey that was established during the early stages of the pandemic outbreak (Phillips et al., 2021). The survey consisted of a baseline (March/April 2020), 3-month (June/July 2020), 12-month (March/April 2021), 18-month (September–November 2021), and 24-month (March/April 2022) follow ups. COPE aimed to gather information about several topics relating to the pandemic, including but not limited to, health behaviours and health and well-being outcomes. The first baseline survey was conducted at the start of the pandemic from 13 March to 14 April, 2020, with 11,112 UK respondents completing the survey. The majority of participants were recruited through HealthWise Wales, which is a large-scale health research initiative based in Wales designed to improve health and healthcare through the active involvement of the population in research (Hurt et al., 2019). Additional participants were recruited through social media platforms, such as Facebook, Instagram and Twitter. This means that most respondents of the COPE study were from Wales (Phillips et al., 2021). The sample was fully longitudinal in that no further participants were recruited after the baseline responses were collected. The responses at the different time points were linked at the individual level using a unique respondent number. Full details of sampling and recruitment are available elsewhere (Phillips et al., 2021). The COPE study received ethical approval from the Cardiff Metropolitan University Applied Psychology ethics panel on 13 March 2020 (Project reference Sta-2707). The panel follows a framework for the Cardiff School of Sport and Health Sciences which aligns with institution-wide procedures approved by Cardiff Metropolitan's University Ethics Committee as well as the British Psychological Society Code of Ethics and Conduct. Consent and confirmed eligibility were provided by participants electronically at the baseline survey. During the COPE 12-month survey, participants were asked for consent to recontact for longer-term follow-up (Project Sta-2707, amendment 3, approved on 5 March 2021)."

This study makes use of the surveys that were conducted at 12 months and at 24 months after the beginning of the COVID-19 pandemic, with analyses restricted to participants who completed an additional 'neighbourhood' module of the COPE survey. The 12-month follow-up survey was conducted from 12 March to 13 April, 2021, with 5327 respondents. This coincided with the roll-out of COVID-19 vaccinations via the National Health Service (NHS England, 2021), while many lifestyle restrictions were still in place across the UK. 'Stay local' guidelines were in place in Wales, with indoor fitness and leisure centres remaining closed (UK Government, 2022). The final 24-month follow up was conducted from 28 March to 28 April 2022, with 4243 respondents. During the time of the 24-month survey, legal COVID-19 restrictions were ending in the UK, seeing the end of final social distancing measures and lifestyle restrictions.

The samples used for the analyses consisted of 3359 participants at 12 months and of 2571 participants at 24 months who completed a 'neighbourhood' module in addition to the core survey questions (subjective health and well-being and health behaviour) at these time points. All respondents who filled out the survey at 24 months also filled out the survey at 12 months. Table 1 presents the characteristics of the two samples respectively. The table shows that women, married people/cohabitees, retirees, and older age groups are over-represented, and that almost half of the population (47.4% and 46.9%) have at least one pre-existing medical condition at 12 months and at 24 months. This reflects the overall profile of the COPE cohort (Phillips et al., 2021). The table further shows that the characteristics of the 12-month and 24-month samples are largely similar. This suggests that attrition has not been systematic, in that there are no specific socio-demographic groups that dropped out from the survey between 12 and 24 months. A power analysis, conducted in G*Power (Faul et al., 2009), shows that a sample of 2571 participants is able to detect very small effect sizes of $f2 = 0.003$ with a power of 0.80 at the 5% significance level (Cohen, 1988).

Table 1
Characteristics of the COPE dataset at 12 months and 24 months after the beginning of the COVID-19 pandemic.

	12 months		24 months	
	n	%	n	%
Access to public green space				
<5 min walk	2137	63.6	1617	62.9
5–10 min walk	807	24.0	629	24.5
>10 min walk	386	11.5	301	11.7
Gender				
Male	1053	31.3	822	32.0
Female	2291	68.2	1742	67.8
Age				
18–40	368	11.0	212	8.2
41–60	1133	33.7	843	32.8
61–70	1178	35.1	966	37.6
71 and older	678	20.1	550	21.4
Working status				
In employment (full-time, part-time, self-employed)	1455	43.3	1036	40.3
Unemployed	211	6.3	149	5.8
Retired	1693	50.4	1386	53.9
Marital status				
Married or living together	2352	70.0	1807	70.3
Single, widowed or separated	1007	30.0	764	29.7
Pre-existing medical conditions				
Yes	1767	52.6	1366	53.1
No	1592	47.4	1205	46.9
Private garden				
Yes	3.090	92.0	2380	92.6
No	268	8.0	190	7.4
Overall	3359	100%	2571	100%

Note: the figures may not always add up to 100% due to missing values and rounding.

2.2. Measures

Subjective wellbeing is the main outcome variable of the study, as measured by three items taken from the SF-36/12 scale (Jenkinson et al., 1997); Item 1: "Have you felt calm and peaceful?", Item 2: "Did you have a lot of energy?", and Item 3: "Have you felt downhearted and blue?". Participants could use a response scale, ranging from 'all of the time' (6) to 'none of the time' (1). Summed score of items 1 and 3 has been shown to be indicative of affective disorders (Gill et al., 2007) with the additional vitality item (Item 2) providing good reliability for the ensuing scale. The developers consider vitality an aspect of emotional/mental wellbeing Jenkinson et al., 1997). The subjective wellbeing scale was created by taking the mean of the three items, after reversing the third item, with lower scores indicating poorer subjective wellbeing (Cronbach's $\alpha = 0.83$ at 12 months, 0.81 at 24 months).

Reported access to public green space was measured using an item derived from the Scottish Household Survey (Scottish Government, 2018). Respondents were asked: "How far away from your home is your nearest green space area? (e.g., park, playing field, public garden, woodland, or other green space)." The response options were: "Less than 5-min walk", "Within a 5–10-min walk", "Within a 11–20-min walk", "Within a 21–30-min walk" and "Do not know". The variable was recoded to differentiate between: 'Less than a 5-min walk', 'Within a 5–10-min walk', and 'More than a 10-min walk' (Poortinga et al., 2021) due to the specific distribution of responses. "Within a 11–20-min walk" and "Within a 21–30-min walk" were combined as there were relatively small number of responses in these two categories. Don't knows ($n = 29$) were treated as missing values.

Physical activity was assessed with a series of questions. Participants were asked to recount the number of minutes of moderate and/or vigorous physical activity they had done in the last seven days. Moderate intensity was defined as "taking some effort and can make you breathe somewhat harder than normal", and vigorous intensity was defined as "taking hard physical effort and can make you breathe much harder than normal". The responses were combined using the international physical activity questionnaire (IPAQ) scoring protocol (Forde, 2018). The mean daily Metabolic Equivalent of Task (MET) minutes were calculated to be used in the analyses. MET minutes are a unit of measure used to quantify the amount of energy expended during physical activities ('Compendium of Physical Activities: An Update of Activity Codes and MET Intensities', 2000). MET minutes express the intensity of different physical activities relative to resting metabolic rate. Activities can then be indicated as multiples of this resting rate. MET scores were log transformed because they were skewed towards lower values.

Sociodemographic characteristics were attained by way of survey questions about the participants' gender, age, marital status, and working status. Other covariates included having any pre-existing medical conditions (yes, no), and having access to a private garden. The latter was measured by asking what option best applied to respondents' homes (response options: 'I have access to my own garden', 'I have access to a communal garden', 'I have access to private outdoor space but not a garden (e.g. balcony, yead, patio area, driveway), and 'I don't have access to a garden or private outdoor space'). A distinction was made between "I have access to my own garden" and all other options to capture the significance of having access to private green space (see also Poortinga et al., 2021). Descriptive statistics for these variables at the 12-month and 24-month timepoints are provided in Table 1.

2.3. Statistical analysis

This study used a regression-based approach to explore the role of physical activity in the association between access to green space and subjective wellbeing at two distinct timepoints during and after the COVID-19 pandemic. This was done by constructing a series of linear regression models, with separate analyses conducted for the 12-month and 24-month samples respectively. Model 1 included physical activity as the dependent variable and reported access to public green space as the independent variable (Objective 1). Model 2a included subjective wellbeing as the dependent variable and reported access to public green space as the independent variable (Objective 2a). Model 2b extended Model 2a by adding physical activity as covariate (Objective 2b). The Sobel test (MacKinnon, 2008) was used to test whether physical activity mediates the association between reported access to public green space and subjective wellbeing.

Objective 3 was addressed by calculating the change in physical activity from 12 to 24 months after the beginning of the COVID-19 pandemic. This was done by subtracting the 12-month physical activity from 24-month physical activity ('Δ physical activity'). A linear regression (Model 3) was then conducted with 'Δ physical activity' as the dependent variable and reported access to public green space as the independent variable. Objectives 4a and 4b were addressed by calculating the change in subjective wellbeing from 12 to 24 months. This was done by subtracting the 12-month subjective wellbeing from the 24-month subjective wellbeing ('Δ subjective wellbeing'). Model 4a included 'Δ subjective wellbeing' as the dependent variable and reported access to public green space as the independent variable (Objective 4a). Model 4b extended Model 4a by adding physical activity at 12 months and the change in physical activity from 12 to 24 months ('Δ physical activity') as covariates (Objective 2b).

The reported access to public green space variable was included as two dummies (representing the '5–10 min' and '>10 min' categories), with '<5 min' as the reference category. Furthermore, all analyses were controlled for gender, age, marital status, employment status, pre-existing medical conditions and access to a private garden. For these socio-demographics the following reference categories were used: Gender (male), Age (18–40), Unemployed, 'Single, widowed or separated', No pre-existing medical conditions, and No access to a private garden. Uncontrolled analyses are provided in the Supplementary Materials, Tables S1–S3. Kolmogorov–Smirnov (KS) tests showed that the residuals only had small deviations from being normally distributed ($D(3313) = 0.05$, $p < 0.001$ for subjective wellbeing at 12 months; $D(2537) = 0.07$, $p < 0.001$ for subjective wellbeing at 24 months; $D(3227) = 0.06$, $p < 0.001$ for physical activity at 12 months; and $D(2431) = 0.07$, $p < 0.001$ for physical activity at 12 months). The KS test becomes highly sensitive with large sample sizes (Hair et al., 1998), as is the case here, and visual inspection of the Q-Q plots indicated near normal distributions. While residual plots did not suggest heteroscedasticity, Breusch-Pagan tests indicated that homoscedasticity could not be assumed ($BP(11) = 27.554$, $p = 0.004$ for subjective wellbeing at 12 months; $BP(11) = 23.633$, $p = 0.014$ for subjective wellbeing at 24 months; $BP(11) = 26.319$, $p = 0.006$ for physical activity at 12 months; and $BP(11) = 21.589$, $p = 0.008$ for physical activity at 12 months). This may lead to biases in the standard error estimates. The models are therefore reported with Huber-White robust standard errors,

All analyses were conducted in R statistical software (version 4.0.2) and RStudio (version 2021.09.0 + 351).

3. Results

3.1. Descriptive results

Fig. 1a shows that physical activity is lower for people living a 5–10-min walk and living more than a 10-min walk away from public green space, as compared to those who live less than a 5-min walk away from a public green space (Table 2). These differences were significant at both the 12-month and at 24-month timepoints (Supplementary Materials, Tables S1 and S2), although physical activity was higher at 24 months than at 12 months overall. This difference was small ($d = 0.12$) but statistically significant ($t = 5.862$, $df = 2{,}458$, $p < 0.001$).

Fig. 1b shows that at both 12 and 24 months, people living a 5–10-min walk and living more than a 10-min walk away from a public green space have a lower subjective wellbeing than those living less than a 5-

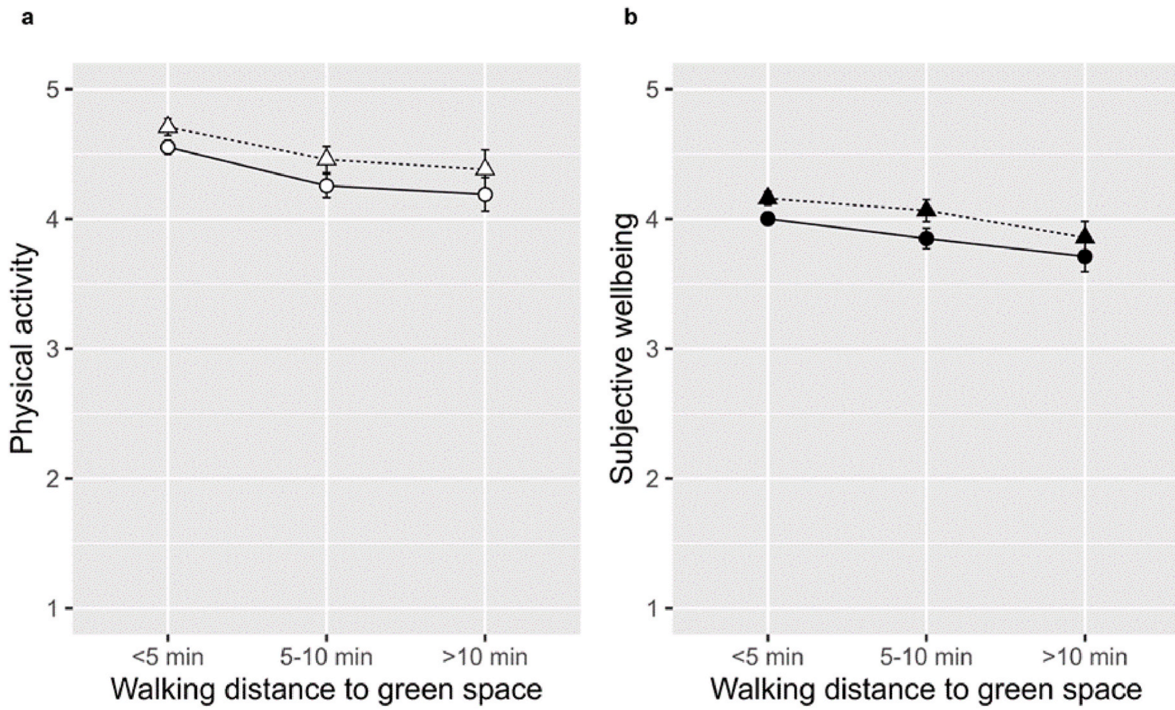

Fig. 1. Mean physical activity and subjective wellbeing according to reported walking distance to public green space at the 12 months (circles) and 24 months (triangles) from the beginning of the COVID-19 pandemic. The error bars show 95% confidence intervals (CIs). Physical activity is shown in log*(daily MET minutes)*.

Table 2
Mean (M) physical activity and subjective wellbeing and their standard deviations (SD) for access to green space categories at 12 months and 24 months after the beginning of the COVID-19 pandemic.

	Physical activity		Subjective wellbeing	
	12 months	24 months	12 months	24 months
	M (SD)	M (SD)	M (SD)	M (SD)
Access to public green space				
<5 min walk	172.2 (195.8)	202.8 (232.8)	4.00 (1.13)	4.16 (1.07)
5–10 min walk	132.8 (167.2)	157.4 (184.6)	3.85 (1.14)	4.06 (1.08)
>10 min walk	125.7 (180.0)	149.8 (184.2)	3.71 (1.16)	3.86 (1.10)
Overall	156.9 (188.7)	184.8 (217.2)	3.93 (1.14)	4.10 (1.08)

Note: M = mean; SD = standard deviation; Physical activity represent daily MET minutes.

min walk away from public green space (Table 2). Overall, subjective wellbeing was higher at 24 months than at 12 months. This difference was small ($d = 0.15$) but statistically significant ($t = 7.382$, $df = 2,567$, $p < 0.001$).

3.2. *Reported access to public green space, physical activity and subjective wellbeing at 12 months*

Table 3 reports the results of the regression analyses (Models 1, 2a and 2b) at the 12-month timepoint. The first column (Model 1) shows that reported access to public green space is associated with physical activity at 12 months, with and without controlling for gender, age, marital status, employment status, pre-existing medical conditions, and access to a private garden. It shows that people living a 5-10-min walk or >10-min walk away from public green space had lower physical activity than those living less than a 5-min walk away from public green space. Women have lower physical activity than men at 12 months, older age groups have higher physical activity than younger age groups; people who are employed or retired have higher physical activity than those

Table 3
Results of linear regression models of physical activity and subjective wellbeing at 12 months after the beginning of the COVID-19 pandemic.

12 months	Physical activity	Subjective wellbeing	
	Model 1	Model 2a	Model 2b
	B (SE)	B (SE), p	B (SE), p
Constant	4.161 (0.128)[b]	3.211 (0.112)[b]	3.286 (0.111)[b]
Access to green space (5–10 min walk)	−0.250 (0.054)[b]	−0.115 (0.043)[b]	−0.065 (0.043)
Access to green space (>10 min walk)	−0.273 (0.071)[b]	−0.239 (0.059)[b]	−0.192 (0.060)[b]
Gender (female)	−0.238 (0.050)[b]	−0.335 (0.041)[b]	−0.288 (0.040)[b]
Age (41–60)	0.122 (0.077)	0.321 (0.068)[b]	0.297 (0.067)[b]
Age (61–70)	0.168 (0.091)	0.605 (0.080)[b]	0.579 (0.080)[b]
Age (71+)	0.143 (0.105)	0.738 (0.089)[b]	0.699 (0.089)[b]
Employed	0.363 (0.081)[b]	0.357 (0.071)[b]	0.269 (0.070)[b]
Retired	0.337 (0.094)[b]	0.544 (0.081)[b]	0.454 (0.080)[b]
Married/Living together	0.133 (0.050)[b]	0.179 (0.042)[b]	0.157 (0.041)[b]
Medical condition	−0.415 (0.045)[b]	−0.410 (0.037)[b]	−0.324 (0.037)[b]
Private garden	0.215 (0.084)[a]	0.212 (0.072)[b]	0.163 (0.071)[a]
Physical activity	–	–	0.198 (0.015)[b]
Observations	3227	3313	3226

Note: B = unstandardised regression coefficient; SE = standard error; Model 1: $R2 = 0.062$ (adjusted $R2 = 0.058$), $F(11, 3215) = 19.2$, $p < 0.001$; Model 2a: $R2 = 0.159$ (adjusted $R2 = 0.156$), $F(11, 3301) = 56.9.4$, $p < 0.001$; Model 2b: $R2 = 0.203$ (adjusted $R2 = 0.199$), $F(12, 3213) = 68.13$, $p < 0.001$.
[a] $p < 0.05$.
[b] $p < 0.01$.

who are unemployed; people who are married people or living together have higher physical activity than those who single, divorced and separated; people who have a pre-existing medical condition have lower physical activity than those who don't have such a condition; and people who have access to a private garden have higher physical activity than those who do not have access to a private garden.

The second column of Table 3 (Model 2a) shows that reported access to public green space is significantly associated with subjective wellbeing at the 12-month timepoint. It shows that people living a 5-10-min walk or >10-min walk away from public green space have lower subjective wellbeing than those living less than a 5-min walk away from public green space. The column further shows that women have lower subjective wellbeing than men; older age groups have higher subjective wellbeing than younger age groups; people who are employed or retired have higher subjective wellbeing than those who are unemployed; people who are married or living together have higher subjective wellbeing than those who are single, widowed or separated; people who have pre-existing medical conditions have lower subjective wellbeing than those who do not have such a condition; and people who have access to a private garden have higher subjective wellbeing than those who do not have access to a private garden. These match the patterns shown for physical activity.

The third column of Table 3 (Model 2b) shows that physical activity is significantly associated with subjective wellbeing, and that the association of access to green space with subjective wellbeing is diminished when controlling for physical activity. The column shows that the parameter for '5–10 min walk' category is rendered non-significant (from B = −0.115 (SE = 0.043) to B = −0.065 (SE = 0.043), and that the parameter for the '>10 min walk' category was reduced from B = −0.239 (SE = 0.059) to B = −0.192 (SE = 0.060), indicating that physical activity partially mediates the association between reported access to public green space and subjective wellbeing. Sobel tests confirmed that this is the case for the '5-10-min walk' (Z = −4.475 (SE = 0.011), p < 0.001) and '> minute walk' (Z = −3.710 (SE = 0.015), p < 0.001) categories.

The mediation model for the 12-month timepoint is summarised in Fig. 2a.

3.3. *Reported access to public green space, physical activity and subjective wellbeing at 24 months*

Table 4 reports the results of the regression analyses (Models 1, 2a and 2b) at the 24-month timepoint. The first column (Model 1) shows that reported access to public green space is significantly associated with physical activity at 24 months, even when controlling for gender, age, marital status, employment status, pre-existing medical conditions, and

Table 4
Results of linear regression models of physical activity and subjective wellbeing at 24 months after the beginning of the COVID-19 pandemic.

24 months	Physical activity	Subjective wellbeing	
	Model 1	Model 2a	Model 2b
	B (SE)	B (SE)	B (SE)
Constant	4.459 (0.162)[b]	3.555 (0.129)[b]	3.584 (0.124)[b]
Green space (5–10 min walk)	−0.224 (0.060)[b]	−0.060 (0.048)	−0.027 (0.048)
Green space (>10 min walk)	−0.268 (0.084)[b]	−0.232 (0.063)[b]	−0.185 (0.063)[b]
Gender (female)	−0.278 (0.057)[b]	−0.296 (0.043)[b]	−0.246 (0.042)[b]
Age (41–60)	0.295 (0.098)[b]	0.156 (0.082)	0.110 (0.080)
Age (61–70)	0.312 (0.112)[b]	0.346 (0.091)[b]	0.290 (0.090)[b]
Age (71+)	0.291 (0.128)[a]	0.330 (0.101)[b]	0.276 (0.100)[b]
Employed	0.258 (0.106)[a]	0.401 (0.082)[b]	0.339 (0.077)[b]
Retired	0.346 (0.116)[b]	0.601 (0.091)[b]	0.515 (0.087)[b]
Married/Living together	0.026 (0.058)	0.153 (0.047)[b]	0.156 (0.046)[b]
Medical condition	−0.377 (0.052)[b]	−0.460 (0.040)[b]	−0.376 (0.040)[b]
Private garden	0.041 (0.101)	0.203 (0.083)[a]	0.197 (0.082)[a]
Physical activity	–	–	0.200 (0.016)[b]
Observations	2472	2539	2417

Note: B = unstandardised regression coefficient; SE = standard error; Model 1: R2 = 0.052 (adjusted R2 = 0.048), F(11, 2460) = 12.3, p < 0.001; Model 2a: R2 = 0.132 (adjusted R2 = 0.128), F(11, 2527) = 34.9, p < 0.001; Model 2b: R2 = 0.186 (adjusted R2 = 0.182), F(12, 2458) = 46.7, p < 0.001.
[a] p < 0.05.
[b] p < 0.01.

access to a private garden. It shows that people living a 5-10-min walk or >10-min walk away from public green space had lower physical activity than those living less than a 5-min walk away from public green space. The physical activity patterns are the same for the socio-demographic variables as at the 12-month timepoint, except for access to a private garden. The column shows that there is no significant difference in physical activity between people who have access to a private garden and those who do not have access to a private garden.

The second column of Table 4 (Model 2a) shows that reported access to public green space is significantly associated with subjective wellbeing at the 24-month timepoint. It shows that people living more than a 10-min walk away from public green space have lower subjective wellbeing than those living less than a 5-min walk away from public green space. The effect for the '5-10-min walk' category is however non-significant. The subjective wellbeing patterns are the same for the socio-demographic variables as at the 12-month timepoint, except for the

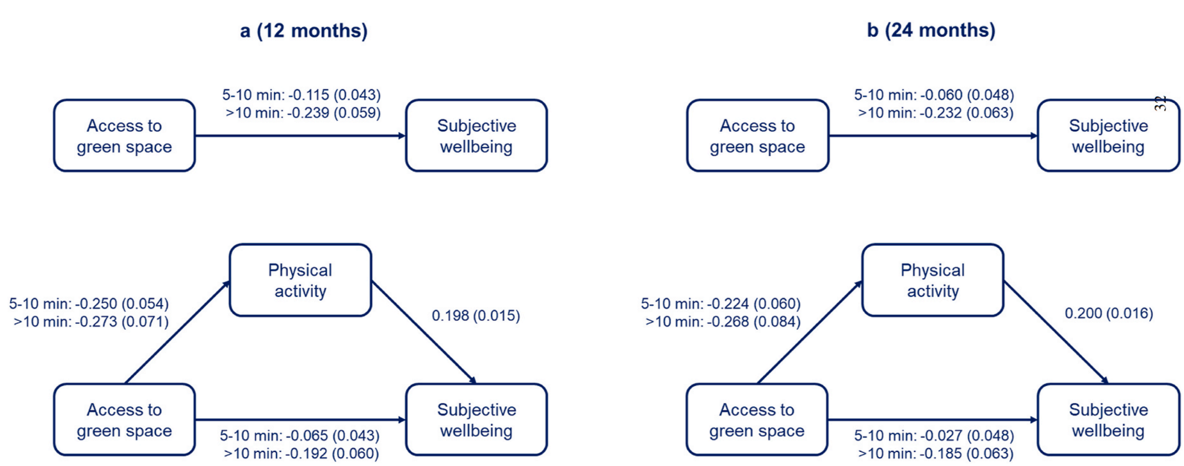

Fig. 2. Mediation model of access to public green space, physical activity and subjective wellbeing at 12 months (a) and 24 months (b) after the beginning of the COVID-19 pandemic. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

41–60 age group. The column shows that the parameter for the 40–61 age groups is non-significant.

The third column of Table 4 (Model 2b) shows that physical activity is significantly associated with subjective wellbeing, and that the association of access to green space with subjective wellbeing is diminished when controlling for physical activity. The column shows that the parameter for the '>10-min walk' category was reduced from B = −0.232 (SE = 0.063) to B = −0.185 (SE = 0.063), indicating that physical activity may partially mediate the association between reported access to public green space and subjective wellbeing. The effect for the '5–10 min' category was already non-significant (B = −0.060 (SE = 0.048) and was further reduced to B = −0.027 (B = 0.048) after controlling for physical activity. Sobel tests suggest that physical activity still acts as a mediator for both green space categories, i.e., Z = −3.523 (SE = 0.013), $p < 0.001$ for 5–10 min and Z = −3.162 (SE = 0.017), $p < 0.001$ for >10 min.

The mediation model for the 24-month timepoint is summarised in Fig. 2b.

3.4. Change in physical activity and subjective wellbeing between 12 months and 24 months

The first column of Table 5 (Model 3) shows that reported access to public green space is non-significantly associated with changes in physical activity from 12 to 24 months (B = −0.008, SE = 0.061 for '5–10 min walk' and B = 0.008, SE = 0.061 for '>10 min walk', respectively), indicating that access to green space is not a factor in the increase in physical activity after the COVID-19 pandemic. The column further shows that gender, age, employment status, pre-existing medical conditions and access to a private garden are also not significantly associated with changes in physical activity from 12 to 24 months.

The second column of Table 5 (Model 4a) shows that reported access to public green space is also non-significantly associated with changes in subjective wellbeing from 12 to 24 months (B = 0.033, SE = 0.039 for '5–10 min walk' and B = 0.026, SE = 0.052 for '>10 min walk', respectively), indicating that access to green space is not a factor in the increase in subjective wellbeing after the COVID-19 pandemic. The column shows that gender, employment status, pre-existing medical conditions and access to a private garden are also not significantly associated with changes in physical activity from 12 to 24 months. However, there were negative parameters for the 61–70 and 71+ age groups. This shows that these age groups saw a smaller increase in subjective wellbeing as compared to the 18–40 age group (who had lower subjective wellbeing at the 12-month timepoint).

The third column of Table 5 (Model 4b) shows that the change in subjective wellbeing from 12 to 24 months is non-significantly associated with physical activity at 12 months (B = 0.012, SE = 0.05). There is however a significant effect for change in physical activity from 12 to 24 months (B = 0.088, SE = 0.015).

Table 5
Results of linear regression models of change in physical activity and change in subjective wellbeing from 12 to 24 months after the beginning of the COVID-19 pandemic.

12–24 months	Δ Physical activity	Δ Subjective wellbeing	
	Model 3	Model 4a	Model 4b
	B (SE)	B (SE)	B (SE)
Constant	0.289 (0.161)	0.183 (0.106)	0.160 (0.108)
Access to green space (5–10 min walk)	−0.008 (0.062)	0.033 (0.038)	0.029 (0.039)
Access to green space (>10 min walk)	0.008 (0.083)	0.026 (0.053)	0.042 (0.055)
Gender (female)	−0.029 (0.057)	0.057 (0.035)	0.060 (0.036)
Age (41–60)	0.153 (0.103)	−0.119 (0.071)	−0.144 (0.072)[a]
Age (61–70)	0.072 (0.115)	−0.226 (0.081)[b]	−0.244 (0.082)[b]
Age (71+)	0.067 (0.115)	−0.371 (0.088)[b]	−0.393 (0.089)[b]
Employed	−0.078 (0.101)	0.094 (0.061)	0.097 (0.063)
Retired	0.045 (0.110)	0.097 (0.067)	0.093 (0.069)
Married/Living together	−0.107 (0.059)	−0.048 (0.037)	−0.033 (0.037)
Medical condition	0.039 (0.053)	−0.040 (0.033)	−0.036 (0.034)
Private garden	−0.176 (0.099)	0.059 (0.065)	0.070 (0.065)
Physical activity (at 12 months)	–	–	0.012 (0.015)
Change in physical activity (from 12 to 24 months)	–	–	0.088 (0.016)[b]
Observations	2431	2537	2429

Note: B = unstandardised regression coefficient; SE = standard error; Model 1: $R2 = 0.006$ (adjusted $R2 = 0.001$), $F(11, 2419) = 1.3$, $p = 0.203$; Model 2a: $R2 = 0.022$ (adjusted $R2 = 0.017$), $F(11, 2525) = 5.1$, $p < 0.001$; Model 2b: $R2 = 0.038$ (adjusted $R2 = 0.033$), $F(13, 2415) = 7.0$, $p < 0.001$.
[a] $p < 0.05$.
[b] $p < 0.01$.

4. Discussion

4.1. Summary of results

The present study examined the associations of reported access to public green space, physical activity and subjective wellbeing at two distinctive timepoints during and after the COVID-19 pandemic. Specifically, it examined whether reported access to public green space is associated with physical activity (Objective 1) and physical activity (Objective 2a) at 12 and 24 months after the beginning of the COVID-19 pandemic, with the aim to examine whether physical activity acts as a mediator between reported access to public green space and subjective wellbeing (Objective 2b). It also examined whether any changes in physical activity (Objective 3) and subjective wellbeing (Objective 4a) between the two time periods are dependent on access to public green space or whether any changes in subjective wellbeing can be explained by changes in physical activity between the two time periods (Objective 4b).

The results show that reported access to public green space was associated with physical activity and subjective wellbeing at both 12-month and 24-month after the beginning of the COVID-19 pandemic. These associations were small but significant. The analyses further showed that physical activity partially mediates the association between reported access to public green space and subjective wellbeing, again at the two time points. The study further observed an increase in physical activity and subjective wellbeing from 12 to 24 months, but no evidence was found that these changes are linked to reported access to public green space or changes in subjective wellbeing. It is therefore likely that the changes in physical activity are due to wider changes, most notably the relaxation of COVID-19 lifestyle restrictions between the two timepoints. At the 24-month timepoint, legal COVID-19 restrictions had mostly ended in the UK, allowing the reopening of indoor exercise facilities such as leisure centres and gyms, with no limitations placed on time spent outdoors. This is in contrast to the 12-month timepoint, when people were still encouraged to work from home and restrictions limiting outdoor exercise and the mixing of households (UK Government, 2022).

The results show that reported access to public green space was only weakly associated with physical activity and subjective wellbeing levels, but that physical activity was a significant mediator of the association. Overall, the results of the literature are mixed, with not all research finding evidence of mediation (e.g., Maas et al., 2008; Richardson et al., 2013). Our findings are in line with Van den Berg et al. (2019), who found that physical activity is a mediator of the relationship between time spent visiting green space and mental health and vitality scores.

The current research contributes new evidence supporting the notion of physical activity as a partial mediator, based upon a large sample of adults from the UK. It represents a first attempt to do this longitudinally at different time points with different levels of restrictions during and after the COVID-19 pandemic. Other research carried out during the pandemic has highlighted the importance of green space in terms of subjective wellbeing (Poortinga et al., 2021; Venter et al., 2021). While it has been suggested that public green spaces were particularly important when restrictions were in place (e.g., Dawwas & Dyson, 2021; Pouso et al., 2021; Soga et al., 2020), the current study found no evidence that the importance of green space differed during and after the pandemic, as the effects were largely comparable for the different time points.

It is yet not clear what the long-term effects of COVID-19 restrictions are in terms of physical activity, but the results of the current study are in line with other research showing that, after an initial decline in physical activity levels at the height of COVID-19 restrictions, physical activity levels were increasing again soon after (Wunsch et al., 2022). It appears that levels of physical activity have increased further two years after the COVID-19 pandemic was declared. It is likely that the reopening of indoor exercise facilities, including gyms, swimming pools and fitness classes has played a role in the increasing physical activity levels across the population, as well as other activities such as (active) travel to schools and workplaces.

4.2. Strengths and limitations

The current study has a number of strengths and limitations. A main strength involves the longitudinal nature of the study design and large sample. The use of multiple timepoints throughout the COPE study allowed for comparisons to be made at different points during and after the COVID-19 pandemic, whereby limitations upon time spent outside and social distancing measures differed. With the 12-month timepoint comprising an adjustment to life under restrictions, if not a full lockdown, and the 24-month timepoint seeing the end of COVID-19 restrictions in the UK, a valuable comparison could be made between physical activity and wellbeing outcomes. In this way, the importance of green space and physical activity were highlighted, demonstrating the importance of 'green exercise' for mental health. While there is an abundance of research reporting the impact of COVID-19 restrictions upon physical activity and exercise, there is limited evidence supporting the long-term implications of the pandemic upon late- and post-pandemic physical activity and subjective wellbeing. In line with this, as far as we are aware, the present study represents the first longitudinal analysis focusing on physical activity as a potential mediator of the relationship between green space and subjective wellbeing, carried out during and after the COVID-19 pandemic.

That being said, the COPE cohort is not representative of the general population. The recruitment resulted in an overrepresentation of female participants, older age groups, and highly educated individuals. This means that it is not possible to generalise the findings and create population estimates (Poortinga et al., 2021). While it is widely acknowledged within the literature that affluent households typically have better access to green space and nature, this is also associated with higher levels of education (Wen et al., 2013). Accordingly, while the majority of participants in the present study reported living within a 10-min walk to local green space, further research is needed to better understand the relationship between green space and wellbeing for lower income neighbourhoods.

The way in which green space has been both conceptualised and measured has varied significantly throughout the literature (Houlden et al., 2018). In the present study, access to green space was measured by way of recording participants perceived walking distance to their closest local green space area, based upon an item derived from the Scottish Household Survey (Scottish Government, 2018). In measuring the variable in this subjective manner, it is possible that responses were influenced by a number of personal characteristics. While objective measures of greenness or natural environment have been highlighted, research has shown individual perceptions of green space as being more strongly associated with physical activity than objective measures (McGinn et al., 2007).

A related limitation encompasses our limited understanding of where participants engaged in physical activity, i.e., whether it took place in local green space or not. It is therefore possible that participants have undertaken activities and exercise somewhere else (e.g., at home or in an urban environment). This represents a limitation of research carried out in this field, with authors hypothesising this may explain the inconsistent evidence supporting an association between green space and physical activity (Markevych et al., 2017). To better understand the role of green space, future studies could ask participants in which setting they are most physically active. Here, it is also important to note that physical activity only partly mediated the relationship between reported access to public green space and subjective wellbeing. This means that there are still other processes at play that were part of the wellbeing effects of green space during COVID-19. It is possible that they were due to reduced exposure to environmental stressors, opportunities for restoration, and/or other form of capacity building, such as increased social interactions (Markevych et al., 2017). It is also possible that simply having views of nature was already beneficial for people's wellbeing during the COVID-19 pandemic (Garrido-Cumbrera et al., 2023).

The study used a subset of items of a standard scale to measure for assessing overall health status. It combined items from the vitality and mental health domain of the SF36 scale to create an internally consistent measure of subjective wellbeing. Subjective wellbeing is however a multi-dimensional construct (Ryff & Keyes, 1995), and it is therefore possible that other measures and/or aspects may produce slightly different effects. Here, it would be useful to explore both hedonic and eudaimonic aspects of wellbeing, and to use scales that were specifically developed to measure them such as the Satisfaction with Life (Diener et al., 1985) or Psychological Well-Being (Ryff & Keyes, 1995) scales, respectively.

4.3. Implications and future research directions

The present research represents the first longitudinal study the associations between reported access to public green space, physical activity and subjective wellbeing conducted over multiple timepoints during and after the COVID-19 pandemic. Research in this field has important implications for supporting mental health through providing better access to green space and increasing opportunity for physical activity, especially during times of crisis, such as the COVID-19 pandemic (Stanhope & Weinstein, 2021). There are noteworthy implications for future town planning initiatives, with the present research highlighting the importance of local green space for mental wellbeing. Accordingly, researchers have emphasised the need for urban planners and designers to prioritise green space in their plans, due to lessons learnt from the COVID-19 pandemic (Ahmadpoor & Shahab, 2021). As such, further longitudinal studies are required to support the current findings; ideally exploring the impact of environmental interventions, such as the construction of new green space, on mental wellbeing outcomes.

The research found a small but significant increase in physical activity between the 12- and 24-month timepoints, which appears to reflect a general pattern resulting from the easing of lifestyles restrictions. This has implications for future public health guidelines during times of potential lockdown or quarantine periods. Gaining an understanding of the factors associated with increased physical activity is important for the development of interventions designed that may help to counter the detrimental effects of restrictions. Further research is needed to establish whether physical activity has been carried out in green space or in other environments (Markevych et al., 2017). This would provide evidence for potential causal relationships between reported access to public green space and subjective wellbeing. Further research is needed to better understand the role of physical activity in conjunction with other potential mediating factors, such as the opportunity to socialise, relaxation and restoration, and reduced exposure to pollutants and stressors. Efforts to disentangle the different mechanisms and their interactions (Markevych et al., 2017) are needed to obtain a more comprehensive understanding of green space-wellbeing association and how that can be used to benefit the resilience of more vulnerable populations.

5. Conclusion

The results of this large-scale, longitudinal study add to the body of evidence supporting the notion that access to public green space provides benefits in terms of subjective wellbeing, and that this is partly mediated by physical activity. The findings were consistent across distinct time points during and after the COVID-19 pandemic, i.e., at 12 months after the beginning of the COVID-19 pandemic, when restrictions were still in place, and at 24 months after the beginning of the COVID-19 pandemic, when legal restrictions had effectively ended across the UK. Physical activity and subjective wellbeing were found to increase from 12 to 24 months, most likely due to easing of lifestyles restrictions. While there was no evidence that that these changes were dependent on access to public space, the benefits of access to public green space in terms of physical activity and subjective wellbeing were apparent both during and after the pandemic. This highlights the enduring importance of high-quality public green space, not only at times of crisis but also at times of relative stability. The observed increase in subjective wellbeing can partly be attributed to changes in physical activity that happened over the same period, confirming the conclusions of recent meta-analyses (Buecker et al., 2021).

CRediT authorship contribution statement

Wouter Poortinga: Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Conceptualization. **Jaiden Denney:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Kirsty Marie Kelly:** Writing – review & editing, Writing – original draft, Conceptualization. **Rebecca Oates:** Writing – review & editing, Writing – original draft, Conceptualization. **Rhiannon Phillips:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition. **Helen Oliver:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Britt Hallingberg:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2024.102376.

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