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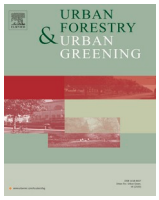

Original Article

Green space visitation: A capacity builder for self-perceived health and subjective wellbeing among urban citizens

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ABSTRACT

Nature and green spaces are proposed to enhance health and wellbeing by for example providing conducive environments for people to engage in activities. Few studies have explored how green space visitation is linked to health and wellbeing through different pathways. We investigated if the amount of vegetation cover and perceived access to green space were associated with frequency of green space visits. Additionally, we examined whether frequency of green space visits was related to self-perceived health and life satisfaction, considering physical and social activity as potential mediators in single and parallel mediation models. We obtained survey data from 5401 citizens living in urban areas of Stavanger and used geographical information systems to compute vegetation cover. Different logistic and linear regression techniques were applied, and mediation analyses were conducted to explore the direct and indirect effects. A higher amount of vegetation cover, as well as good perceived access to green space, were associated with more frequent green space visits. Residents who perceived good access had 2.92 (95 % CI: 2.50, 3.42) times higher odds of visiting green spaces more frequently. Physical and social activity served as mediators in associations between green space visitation and the outcomes self-perceived health and life satisfaction. The mediation effect was enhanced in the parallel mediation models. This study reinforces the importance of having access to urban vegetation and green space. To promote positive public health outcomes, green spaces should be developed with functions that encourage both physical and social activities.

1. Introduction

The urban landscape and its form and functions shape human activity and can offer avenues for promoting health (Frank et al., 2019). One such avenue is urban green space. Although many people choose a life in the city to be close to work and all the facilities that a city has to offer, research has shown that nature and urban green spaces are essential for public health in cities (Browning et al., 2022; Remme et al., 2021; Yang et al., 2021). Thus, the Nordic countries have joined forces to strengthen the development of greener and more socially sustainable cities to face pressing public health challenges and the climate emergency (Nordic Council of Ministers, 2021). This uniting of forces also involves research collaboration, and the current study, utilizing public health survey data along with geographical information systems (GIS) technology, descends from a project (NORDGREEN) that aimed to expand the knowledge base linking green space to health and wellbeing in the Nordic region (Nordregio, 2023).

Evidence accumulated over the last three decades have demonstrated that greater exposure to green space is advantageous for health and wellbeing (Browning et al., 2022; Markevych et al., 2017; Marselle et al., 2021; Rojas-Rueda et al., 2019; Wolf et al., 2020; Yang et al., 2021). Specifically, Barboza et al. (2021) have estimated that fulfilling the WHO recommendation of access to green spaces within a 300-meter distance from residence could prevent almost 43.000 deaths annually in Europe. Potential explanations to these favourable numbers can be provided by looking closely at the ways in which green space is asserted to benefit human health and wellbeing (Markevych et al., 2017; Marselle et al., 2021). According to the frameworks by Markevych et al. (2017) and Marselle et al. (2021), green space and vegetation can reduce harm by mitigating exposure to various environmental hazards like heat, noise, and air pollution. Nature also has restoring capacities by acting as a resource for psychological restoration and stress recovery.

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Furthermore, green space is proposed to be a capacity builder by supporting physical activity and by providing a setting for people to meet and socialize in cities. Despite all these renowned assets of urban nature and green space, crucial, yet challenging, research efforts remain to better understand and explain the various ways in which nature and green space can promote health and wellbeing (Browning et al., 2022; Markevych et al., 2017; Marselle et al., 2021; Yang et al., 2021). Inquiries into how nature and green space can reduce harm, be restorative and build capacity among urban citizens have been stressed as particularly important for future research (Remme et al., 2021). In this study, we investigate visits to green spaces as a capacity builder for self-perceived health and subjective wellbeing.

For green spaces to serve as capacity builders, people must have access to nature and green spaces that they can use within their neighborhoods. One of the most influential factors on green space usage addressed in several studies is distance to the nearest green space from home (Schipperijn et al., 2010; Stigsdotter et al., 2010). The study by Schipperijn et al. (2010) showed that inhabitants in Denmark, another Nordic country, who resided within 300 m from a green space were three times more likely to use green spaces several times a week compared to those who lived more distant from such spaces. However, the 300-meter recommendation (Konijnendijk, 2023), which is heavily applied in policy and practice (Nordh and Olafsson, 2021), has its limitations. For example, Schindler et al. (2022) found that people commonly travel further than 300 m to get to the green spaces they use the most. Importantly, objectively measured access to green space is not equal to residents' perceived access (Nordh et al., 2024), and green space usage can be linked to a variety of green space types or qualities (Knobel et al., 2021), as well as characteristics of the users, such as occupational status (Fischer et al., 2018) and nature orientation (Lin et al., 2014). In this study, we therefore target the amount of urban vegetation and perceived access to green space as two potential predictors of green space visitation.

To further examine whether green space visits can nurture self-perceived health and subjective wellbeing among urban citizens, we developed a conceptual model depicting the relationships between green space visitation, physical and social activity, self-perceived health, and life satisfaction (Fig. 1). Since our aim was to address questions of how and why relationships between green space visits and both self-perceived health and life satisfaction exist, physical and social activity were conceptualized as mediators (MacKinnon and Luecken, 2008). Our model, along with our conceptualization of physical and social activity as mediators, is based on existing frameworks that propose explanations for how green space benefits human health and wellbeing (Markevych et al., 2017; Marselle et al., 2021). As visualized, we hypothesized direct associations between green space visitation and both self-perceived health and life satisfaction. Additionally, we postulated that the overall effect of green space visits on self-perceived health and life satisfaction is mediated through engagement in physical and social activity (Fig. 1). The empirical basis for all the proposed links will be demonstrated below.

To date, numerous studies have found positive relations between exposure to green space and both self-perceived health (de Jong et al., 2012; Orban et al., 2017; Stigsdotter et al., 2010; Twohig-Bennett and Jones, 2018) and subjective wellbeing among adults (Houlden et al., 2018; White et al., 2013; Xu et al., 2022). Further, there is significant evidence to support that access to and use of green spaces increase physical activity (Akpinar and Cankurt, 2017; Juul and Nordbø, 2023; Kaczynski et al., 2009; Maddock and Frumkin, 2025; Wang et al., 2019), as well as social interactions, contact and support (Huang and Lin, 2023; Jennings and Bamkole, 2019; Kruize et al., 2020), in the adult population. Moreover, involvement in both physical and social activities are well known to foster good health and wellbeing (Ekelund et al., 2019; Holt-Lunstad, 2021; Marquez et al., 2020). Given this strong evidence base, it is both relevant and essential to explore whether visiting green spaces can build capacity for health and wellbeing by promoting physical activity and facilitating social contact (Markevych et al., 2017; Marselle et al., 2021).

Although many studies have attempted to unravel how nature and green spaces are linked to health and wellbeing through intermediate variables, an extensive review has revealed several research gaps (Dzhambov et al., 2020), which we aim to address in this study. Firstly, there is paucity of studies that explicitly examine whether visiting green spaces is linked to self-perceived health and subjective wellbeing through engagement in physical and social activities (Dzhambov et al., 2020). Previous studies have mainly assessed exposure in terms of distance to, or the amount of, green space in the neighborhood, without considering whether these green spaces are actually visited (Dzhambov et al., 2020). The few studies that have measured green space visitation have not considered physical and social activity as mediators (Carrus et al., 2015; Dzhambov et al., 2018; Korpela et al., 2014; Panno et al., 2017; Zijlema et al., 2017), with one exception (Van den Berg et al., 2019). Anyhow, Van den Berg et al. (2019) did not focus on self-perceived health or life satisfaction as outcomes. Additionally, the Nordic urban context has not been considered in any of the aforementioned studies, and only a few have performed both single and parallel mediation analyses (Dzhambov et al., 2018; Korpela et al., 2014; Zijlema et al., 2017).

The Nordic urban context makes an interesting case for examining linkages between green space visitation and both self-perceived health and life satisfaction for a couple of reasons. First, accessibility to nature is high even in urban areas where densification, as a result of population growth, often threatens the amount of available green space (Aamodt et al., 2023). Second, all the Nordic countries have strong traditions for outdoor recreation, and nature and green spaces a commonly used for a variety of activities (Dervo et al., 2014; Gelter, 2000). This may indicate that green spaces and visits of such spaces could be a strong capacity builder for health and wellbeing among Nordic city dwellers. However, as far as we know, no existing Nordic studies have examined these linkages (Dahlkvist et al., 2016; de Jong et al., 2012; Nielsen and Hansen, 2007). This highlights the need for additional studies from the Nordic region to address whether visiting green spaces can support

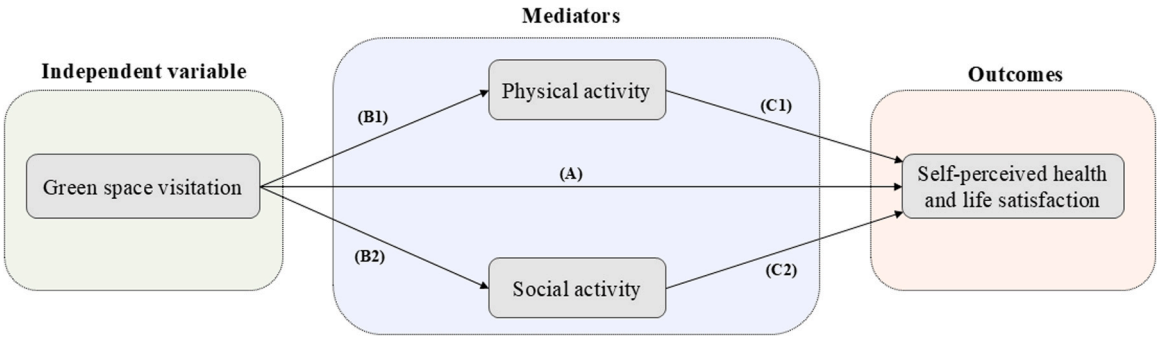

Fig. 1. A conceptual model of green space visitation as a capacity builder for self-perceived health and life satisfaction through physical and social activity.

health and wellbeing through engagement in activities. The key contributions of this paper include providing novel evidence from the Nordic context, assessing life satisfaction as an outcome variable, and considering both single and parallel mediation through physical and social activity. Enhanced knowledge on green space visitation as a viable capacity builder can eventually provide stronger recommendations for policy and practice on how to support public health through urban planning and design. Due to dwindling green space resources in more densely populated areas, knowledge about planning, design and management of green infrastructure that realizes diverse functions within limited space is crucial in urban areas (Haaland and van den Bosch, 2015). Accordingly, this paper had a two-folded aim.

- First, we aimed to examine if the amount of urban vegetation and perceived access to neighborhood green space were associated with the frequency of green space visits.
- Second, we aimed to investigate whether the frequency of green space visits was related to self-perceived health and life satisfaction, and whether these relationships were mediated through physical and social activity using both single and parallel mediation models.

2. Material and methods

2.1. Context of the study

This study was conducted within the frames of the project NORDGREEN – Smart Planning for Healthy and Green Nordic Cities. The project has engaged with six municipalities in the Nordic region to develop knowledge for well-designed green spaces that support the residents' health and wellbeing (Nordregio, 2023). One of the participating municipalities, Stavanger in Norway, was chosen as the study area for this inquiry based on the availability of rich population level data on green space visitation, participation in activities, self-reported health, and wellbeing.

The city and municipality of Stavanger is located along the coast in the southwestern part of Norway and is the administrative and economic centre of Rogaland County (Fig. 2). Stavanger has close to 147 000 residents and is the fourth most populated city in Norway. The municipality is divided into nine districts covering multiple islands and more dense areas on the mainland (Statistics Norway, 2024). Although the municipal master plan has weaknesses in linking green space and health (Sunding et al., 2024), the current municipal green plan has a strong focus on preserving and developing the green infrastructure in the city for recreation, physical activity and social purposes (Stavanger municipality, 2023).

2.2. Data sources

A cross-sectional study design was applied. An objective measure of urban vegetation cover was computed within postal code areas of Stavanger using GIS. This measure was linked to survey data obtained from the Norwegian County Public Health survey in Rogaland using postal codes as the linkage key. The survey was carried out by the Norwegian Institute of Public Health on behalf of the Rogaland county council in autumn 2020. Information about the survey has been published elsewhere (Skogen et al., 2020). An overview of the selection of survey questions from the Norwegian County Public Health survey that were used in this study is provided as supplementary material (Table S1). Further details about the sample and variables applied is provided below.

2.3. Participants

A representative sample of 90 215 inhabitants aged $\geq$ 18 years in Rogaland county was drawn from the National Population Register. After excluding inhabitants with unverified contact information, those reserved from participating, or deceased, 77 889 residents were invited by the Norwegian Institute of Public Health to complete an electronic survey by SMS and email. A total of 35 191 (45.2 %) adults responded to the survey (Skogen et al., 2020), of which we obtained data for all respondents residing in Stavanger municipality (n = 7057). Due to our urban focus, participants living in the districts of Rennesøy and Finnøy were excluded (n = 1387) as these districts are islands characterized by rural areas with mainly agricultural land and few inhabitants. Further,

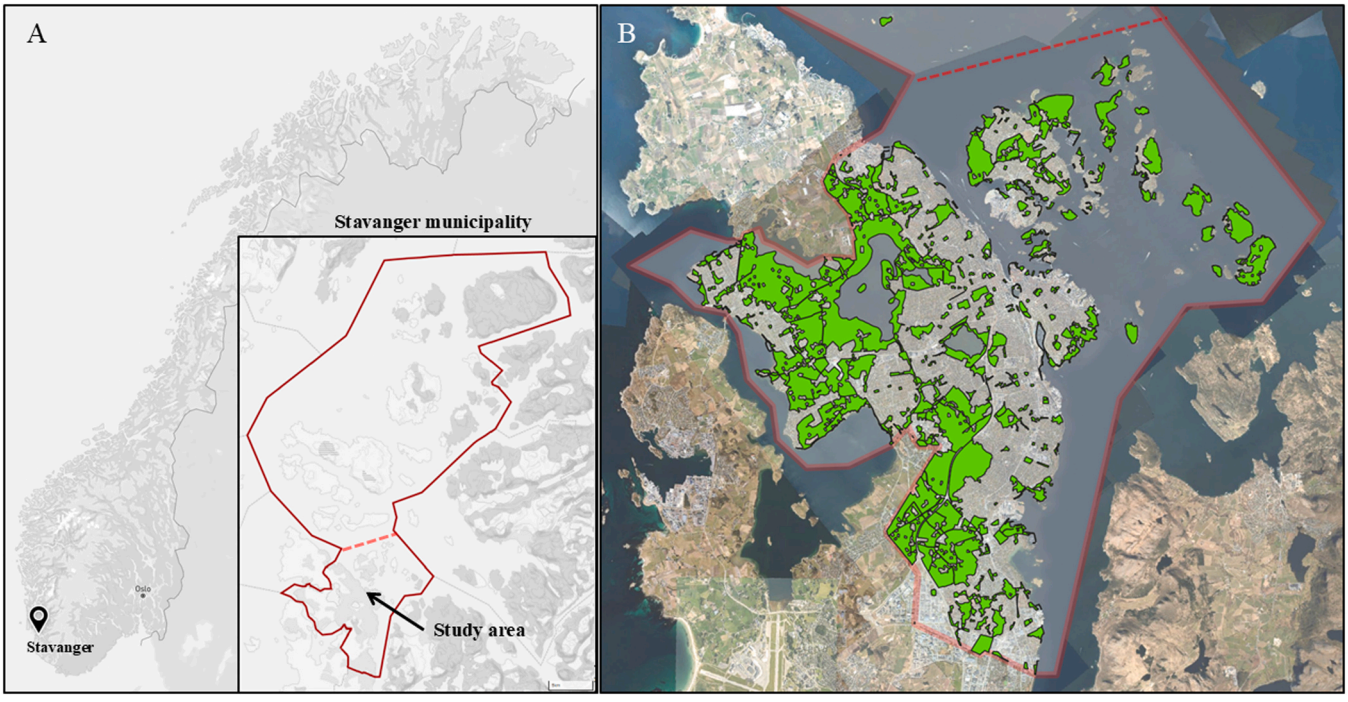

Fig. 2. Location and overview of Stavanger municipality and the urban study area (A), along with a map highlighting the green surroundings within the study area (B).

we excluded respondents with missing data on all key variables (education, marital status, ethnicity, perceived green space access, green space visits, physical activity, social activity with friends, life satisfaction, and self-perceived health; n = 269), resulting in an analytical sample of 5401 adult citizens residing in urban districts of Stavanger.

2.4. Urban vegetation cover

We used an objective indicator to quantify the amount of urban vegetation cover within each participant's postal code area. This measure was computed in Quantum GIS (version 3.4.1) using the Normalized Difference Vegetation Index (NDVI), which is a validated and commonly used indicator for determining vegetation in pixels or grids (Rhew et al., 2011; Song et al., 2019). The principle underlying NDVI is that different surfaces reflect red and near-infrared light (NIR) in different ways, and green vegetation reflects more NIR compared to non-vegetated surfaces (Rhew et al., 2011). Vegetation data derived from the Sentinet-3 satellite and was downloaded from the Copernicus websites (Copernicus Global Land Service). We downloaded images taken each fortnight from April 2021 to July 2021. For each pixel in Stavanger (250 ×250 m resolution), the magnitude of red and NIR was provided, and these figures were added to the formula (NIR-Red)/(NIR+Red) to compute NDVI values. The maximum value for each pixel was selected to represent the greenest period based on the approach used by Barboza et al. (2021). Lastly, a mean NDVI value was computed for each postal code area. The NDVI values range from –1 (representing e.g., water bodies and ice) to + 1 (representing only green vegetation). As there were no negative values in our data, the mean values range from 0 to 1, with values close to zero indicating grey surfaces and scores close to 1 indicating more dense green vegetation. This variable was treated as a continuous independent variable in the regression analyses.

2.5. Variables derived from the public health survey

2.5.1. Perceived access to green space

The citizens' perceived access to neighborhood green space were rated on a five-point Likert scale from 1 (very good) to 5 (very poor). This variable was reverse coded and dichotomized into "poor" (i.e., scores 1–3) and "good" (i.e., scores 4–5) perceived access before it was entered into the statistical models as an independent variable. The response option "don't know" was treated as missing.

2.5.2. Frequency of green space visits

We constructed an ordinal variable with five categories capturing frequency of green space visits: "daily or almost daily", "3–5 times/week", "1–2 times/week", "1–3 times a month" and "seldom/ never". The response option "don't know" was treated as missing. Frequency of green space visits was treated as a dependent variable for addressing the first aim, while it was defined as an independent variable when fitting regression models to examine the second aim.

2.5.3. Potential mediators

The participants' physical activity levels were assessed using a variable with four categories that captured weekly frequency of exercise: "seldom/never", "once a week", "2–3 times/week" and "4 times or more/week". The frequency of social activity with friends outside of the family was recoded into a variable with four categories: "about every day", "weekly", "monthly" and "seldom". The response option "I don't have any good friends" had limited responses. Due to the significant deviation in wording from the other response options, responses in this category were treated as missing for comparability. The frequency of engagement in both physical and social activity were considered potential mediators in this study.

2.5.4. Self-perceived health

The respondents rated their overall health on a five-point Likert scale from 1 (very good) to 5 (very poor). This variable was reverse coded and dichotomized into "poor" (i.e., scores 1–3) and "good" (i.e., scores 4–5) health before it was included in the statistical models as an outcome variable.

2.5.5. Subjective wellbeing

People's cognitive and affective evaluations of their life and emotional state form the basis for the subjective dimension of wellbeing. In this study, we applied a measure of life satisfaction to capture subjective wellbeing as commonly used in existing research (OECD, 2020). The respondents were asked to rate their general satisfaction with life on a scale from 0 (very dissatisfied) to 10 (highly satisfied). Life satisfaction was used as a continuous outcome variable in the analyses.

2.5.6. Covariates

The socio-demographic variables age, gender, educational level, marital status, and ethnicity derived from the survey data and were included as covariates in order to account for potential confounders. All covariates were provided as categorical variables. Age was recoded into four categories (i.e., 18–29, 30–49, 50–69 and $\geq$ 70 years), while educational level was recoded into "high school or less", "university $<$ 4 years" and "university $\geq$ 4 years". Marital status was treated as a dichotomous variable (i.e., partner/single). Immigrant background was obtained as a dichotomized variable capturing whether the respondent or at least one of the parents were born outside Norway (i.e., yes/no).

2.6. Statistical analysis

The statistical analyses were run in Jamovi version 2.3.18 and R version 4.3.2, and we determined a significance level of $\alpha = 0.05$. Descriptive statistics were run to categorize, calculate, and summarize features of the data and the sample. For categorical variables, descriptive results are presented as frequencies and proportions, while mean values along with standard deviations (SD) are given for continuous variables.

To address the first research aim, we applied ordinal logistic regression to investigate if the amount of urban vegetation and perceived access to green space were related to frequency of green space visits. Prior to running ordinal regression, the proportional odds assumption was tested using the Brant Test (Brant, 1990; Liu et al., 2023), which indicated that the assumption was not violated. Separate models were fitted for the two independent variables urban vegetation cover and perceived access to green space. Crude and adjusted odds ratios (OR) with corresponding 95 % confidence intervals are reported from these analyses.

Fig. 1 portrays the relationships that formed the basis for our regression modeling approach to address the second aim. Preceding the mediation analyses, initial analyses of associations between variables at each path were conducted. Frequency of green space visits was regressed on self-perceived health and life satisfaction using binary logistic and linear regression, respectively (Path A, Fig. 1). We applied ordinal logistic regression to estimate associations between frequency of green space visits and both physical and social activity (Paths B1 and B2, Fig. 1) using the *polr* command from the MASS package in R. As previously, the proportional odds assumption was tested. To assess associations between each mediator and the two outcomes self-perceived health and life satisfaction, we fitted binary logistic and linear regression models, respectively (Path C1 and C2, Fig. 1). Crude and adjusted estimates (OR and unstandardized B) are reported along with 95 % confidence intervals.

Subsequently, we used the mediation package and its *mediate* command in R to fit four single and two parallel mediation models based on the counterfactual approach (Imai et al., 2010; VanderWeele, 2016). This approach was chosen to decompose the total effect of green space

visits on self-perceived health and life satisfaction into direct and indirect effect estimates using physical and social activity as mediators (VanderWeele and Vansteelandt, 2009). The following pathways from green space visits to self-perceived health and life satisfaction were examined: (1) direct path through neither of the mediators (path A), (2) indirect path through physical activity (path B1 and C1), (3) indirect path through social activity (path B2 and C2) and (4) indirect path through both physical and social activity (path B1/B2 and C1/C2).

In models with self-perceived health as the outcome, the direct and indirect estimates were modelled by binary and ordinal logistic regression and computed for different frequencies of green space visits with seldom/never as the reference group. Ordinal logistic regression was used to assess the relationship between frequency of green space visits and each mediator. In the single mediation models, binary logistic regression was implemented for self-perceived health conditional on green space visits and each mediator. In the parallel mediation model, both mediators were entered simultaneously. All covariates were included in the models. Since the outcome was not rare, estimates were derived from the log-link function and are displayed as log odds with corresponding 95 % CI (VanderWeele, 2016) obtained through quasi-Bayesian Monte Carlo simulations with 1000 resamples (Tingley et al., 2014).

In models with life satisfaction as the outcome, the direct and indirect estimates were derived using ordinal logistic and linear regression techniques. As for the previous mediation models, estimates were computed for different frequencies of green space visits with seldom/never as reference, and we applied ordinal logistic regression to assess associations between frequency of green space visits and each mediator. In the single mediation models, linear regression models were fitted for life satisfaction conditional on green space visits and each mediator separately, including the set of covariates. In the parallel mediation analysis, both mediators were entered in the model. From these mediation models, we report unstandardized regression coefficients (B) with corresponding 95 % confidence intervals (CI) obtained through quasi-Bayesian Monte Carlo simulations with 1000 resamples (Tingley et al., 2014).

2.7. Ethics approval

Prior to data collection, the Norwegian Institute of Public Health collected electronically signed informed consent from all participants. We obtained additional approval for the use of data and the linkage of GIS variables from the Norwegian Agency for Shared Services in Education and Research (ref. no. 314018).

3. Results

3.1. Descriptives for key variables

Table 1 presents the socio-demographic characteristics of the sample of adult citizens residing in Stavanger along with descriptives for key study variables. There was a slight preponderance of female respondents (53.9 %). The majority of the participants aged between 30 and 69 years (73.2 %), had a university degree (61.8 %) and a partner (76.6 %), and were of Norwegian background (81.0 %) (Table 1). As indicated by the mean NDVI score (0.65, SD=0.13), the amount of urban vegetation was generally high. All respondents lived in neighborhoods that had some vegetation (range NDVI 0.26–0.87), and the majority perceived their access to green space as good (87.6 %) (Table 1). Just above one third reported that they visited green spaces in their neighborhood between 3 and 5 times/week or daily (34.2 %). Almost three quarters of the respondents engaged in physical activity two times or more per week (74.0 %). It was most common to meet friends outside of family on a weekly basis (48.9 %). As many as 78.8 % perceived their health as good, and overall, the citizens were satisfied with their life in general (Table 1).

Table 1
Sociodemography and descriptive statistics on key study variables (n = 5401).

Socio-demographic characteristics	Categories	
Gender, n (%)	Male	2491 (46.1)
	Female	2910 (53.9)
Age groups, n (%)	18–29	896 (16.6)
	30–49	1975 (36.5)
	50–69	1981 (36.7)
	70 +	549 (10.2)
Educational level, n (%)	High school or less	2061 (38.2)
	University < 4 years	1318 (24.4)
	University ≥ 4 years	2022 (37.4)
Marital status, n (%)	Partner	4139 (76.6)
	Single	1262 (23.4)
Immigrant background, n (%)	Yes	1010 (18.7)
	No	4391 (81.3)
Vegetation and green space variables		
NDVI, mean (SD)		0.65 (0.13)
Perceived access to green space, n (%)	Poor	668 (12.4)
	Good	4733 (87.6)
Green space visits, n (%)	Seldom/never	1005 (18.6)
	1–3 times/month	1184 (21.9)
	1–2 times/week	1361 (25.2)
	3–5 times/week	926 (17.1)
	Daily	925 (17.1)
Mediators		
Physical activity, n (%)	Seldom/never	673 (12.5)
	Once a week	728 (13.5)
	times/week	1955 (36.2)
	≥ 4 times/week	2045 (37.8)
Social activity with friends, n (%)	Seldom/never	584 (10.8)
	Monthly	1689 (31.3)
	Weekly	2641 (48.9)
	Almost daily	487 (9.0)
Health and wellbeing measures		
Self-perceived health, n (%)	Poor	1145 (21.2)
	Good	4256 (78.8)
Life satisfaction, mean (SD)		7.52 (1.94)

3.1.1. Vegetation and perceived access to green space as predictors of green space visits

We found a positive relationship between the amount of urban vegetation and frequency of green space visits among citizens in Stavanger (Table 2). Specifically, higher amounts of vegetation were related to a greater likelihood of more frequent green space visits. A one-unit increase in the NDVI-score increased the odds of visiting green spaces more frequently by 2.11 (95 % CI: 1.44, 3.08) compared to those who seldom/never visited green spaces. Likewise, the regression analyses revealed a positive association between perceived access to green space and frequency of green space visits (Table 2). Participants who reported good perceived access to neighborhood green spaces had 2.92 (95 % CI: 2.50, 3.42) higher odds of more frequent green space visits compared to residents reporting poor access. There was a slight decrease in the odds ratios after all covariates were entered into the models, but the estimates remained significant (Table 2). When comparing the odds ratios, we see that the estimates were slightly stronger for perceived access to green space as a potential predictor of green space visits compared to the amount urban vegetation.

3.2. Results from initial analysis of associations between variables at each path

The frequency of green space visits was significantly related to both good self-perceived health and higher life satisfaction score (Path A, Table S2). Citizens who visited green spaces 3–5 times a week had 2.20 times higher odds of reporting good health compared to participants who seldom/never visited green spaces. Similarly, visiting green spaces 3–5 times/week was associated with an increase in the life satisfaction score by 0.58 (95 % CI: 0.42, 0.75). Looking at the results on Path B1 and B2 (Table S2), we found that the frequency of green space visits was positively associated with both physical and social activity. Citizens who

Table 2
Crude and adjusted associations between urban vegetation (NDVI), perceived access to green space and frequency of green space visits (n = 5401).

	OR (95 % CI) for green space visits	
	Crude Model 1	**Crude model 2**
NDVI	2.86 (1.97, 4.17)	
Perceived access		
Poor		1
Good		3.65 (3.13, 4.25)
	OR (95 % CI) for green space visits	
	Adjusted model 1[a]	**Adjusted model 2**[a]
NDVI	2.11 (1.44, 3.08)	-
Perceived access		
Poor	-	1
Good		2.92 (2.50, 3.42)
Gender		
Male	1	1
Female	1.22 (1.11, 1.34)	1.18 (1.08, 1.31)
Age groups		
18–29	1	1
30–49	1.84 (1.59, 2.13)	1.63 (1.41, 1.90)
50–69	2.78 (2.39, 3.22)	2.36 (2.03, 2.75)
70 +	2.89 (2.37, 3.52)	2.45 (2.01, 3.00)
Educational level		
High school or less	1	1
University < 4 years	1.30 (1.15, 1.47)	1.29 (1.14, 1.46)
University ≥ 4 years	1.57 (1.40, 1.76)	1.56 (1.39, 1.75)
Marital status		
Partner	1	1
Single	0.82 (0.73, 0.92)	0.82 (0.72, 0.92)
Immigrant background		
Yes	1	1
No	1.05 (0.93, 1.19)	1.04 (0.92, 1.18)

[a] Adjusted for gender, age, educational level, marital status, and immigrant background

visited green spaces 3–5 times/week had 5.87 times higher odds of engaging more frequently in physical activity compared to participants who seldom/never visited green spaces. Those who visited green spaces 3–5 times/week were also more likely to engage in social activity. Specifically, the odds ratio for participating in social activity for those visiting green spaces 3–5 times/week was 1.96 (95 % CI: 1.65, 2.34) compared to those who seldom/never visited green spaces. Significant associations between the two mediators and both self-perceived health and life satisfaction (Path C1 and C2) were also found (Table S2). For example, participants who engaged in physical activity ≥ 4 times per week had 4.27 times higher odds of reporting good health, and they had 0.84 higher life satisfaction score, compared to those who seldom/never engaged in physical activity. Likewise, citizens who met friends outside of the family almost daily had 3.23 times higher odds of reporting good health, and they had 1.57 higher life satisfaction score, compared to participants who seldom/never participated in social activity.

3.2.1. Do physical and social activity mediate the association between green space visits and self-perceived health?

Figs. 3 and 4 display the results of the association between green space visits and self-perceived health that could be attributed to physical and social activity, respectively. We observed significant total effects of green space visits on self-perceived health (Figs. 3 and 4). In the model with physical activity as the mediator (Fig. 3), the log odds indicate that the probability of reporting good health was higher with more frequent green space visits. While the direct association was not significant, the indirect pathway through physical activity showed significant estimates across all frequency levels (Fig. 3). Depending on green space visitation frequency, we found that 74.1–76.0 % of the association between green space visits and self-perceived health was significantly mediated through engagement in physical activity. For example, we see that the total effect on self-perceived health for citizens visiting green spaces 3–5 times/week was 0.10 (95 % CI: 0.07, 0.13) compared to those who seldom/never visit green space, of which a log odds of 0.08 (95 % CI: 0.06, 0.09) was attributed to the physical activity pathway (Fig. 3). In the model with social activity as the mediator (Fig. 4), both the direct and the indirect estimates reached significance. However, the indirect effect was low, and the proportion of the association between green space visits and self-perceived health mediated by social activity was lower than for physical activity, with 10.0 % across all visitation frequency levels.

The parallel mediation model, which included both physical and social activity simultaneously, revealed significant total effects similar to those found in the single models. The direct relations between frequency of green space visits and self-perceived health remained non-significant (Fig. 5). Depending on green space visitation frequency, we

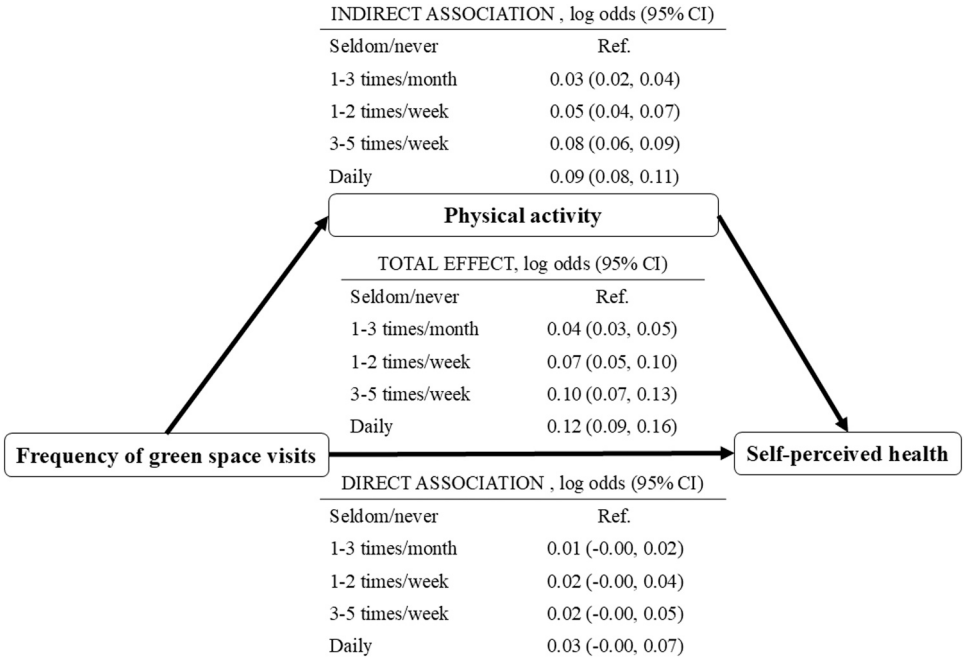

Fig. 3. Total, direct and indirect estimates for the relationship between green space visits and self-perceived health with physical activity as the mediator (n = 5401).

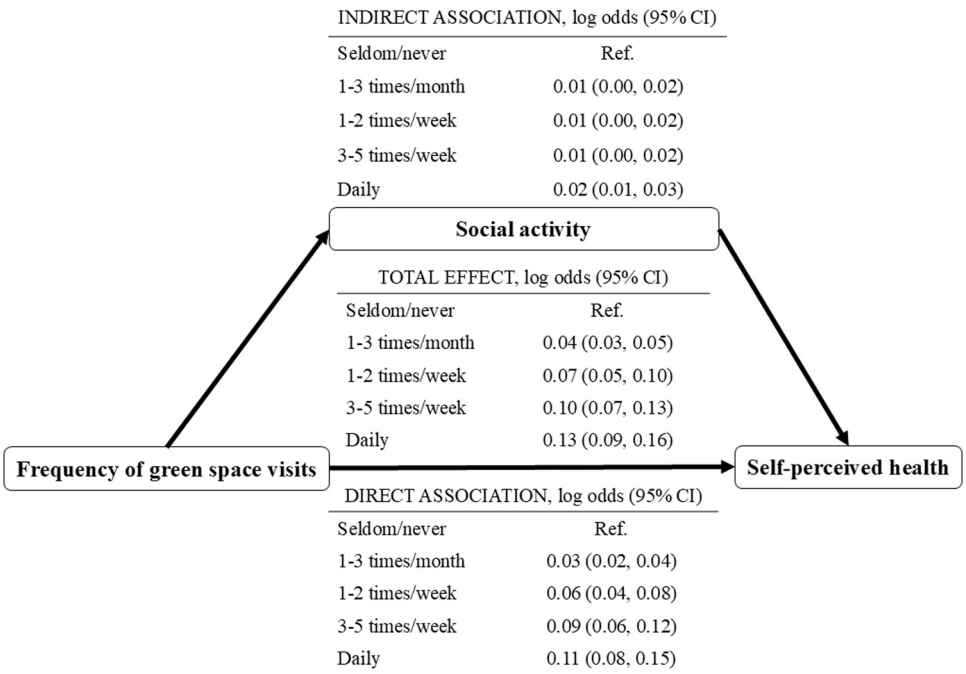

Fig. 4. Total, direct and indirect estimates for the relationship between green space visits and self-perceived health with social activity as the mediator (n = 5401).

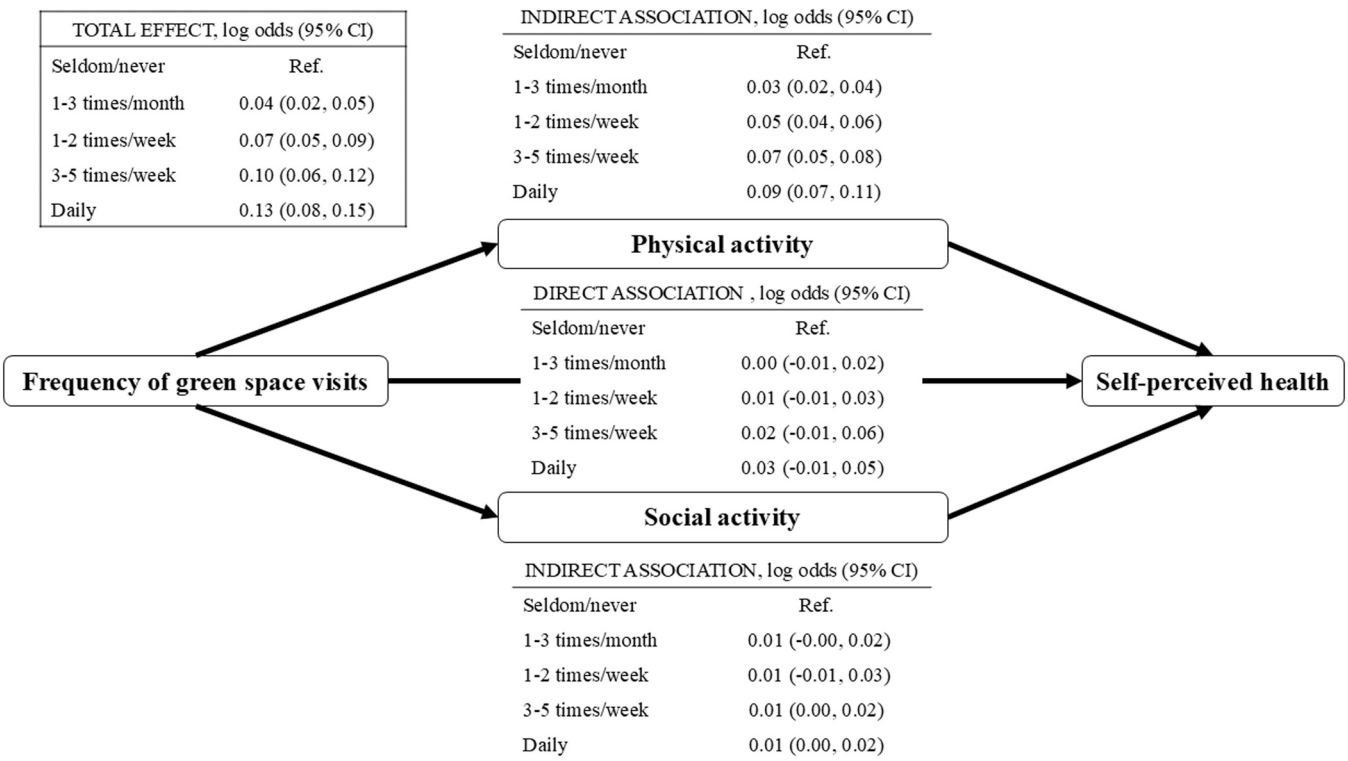

Fig. 5. Results from parallel mediation analysis with physical and social activity as mediators in the relationship between green space visits and self-perceived health.

observed that 75.0–85.7 % of the association was mediated through both physical and social activity, indicating that the mediation effect was somewhat enhanced in the parallel model. However, significant indirect effects were only found for physical activity (Fig. 5).

3.2.2. Do physical and social activity mediate the association between green space visits and life satisfaction?

Results from the single mediation models showed a similar pattern for the association between green space visits and life satisfaction (Figs. 6 and 7). In the model with physical activity as the mediator (Fig. 6), no significant direct association was observed. The indirect estimates suggested that physical activity accounted for 68.7–71.3 % of

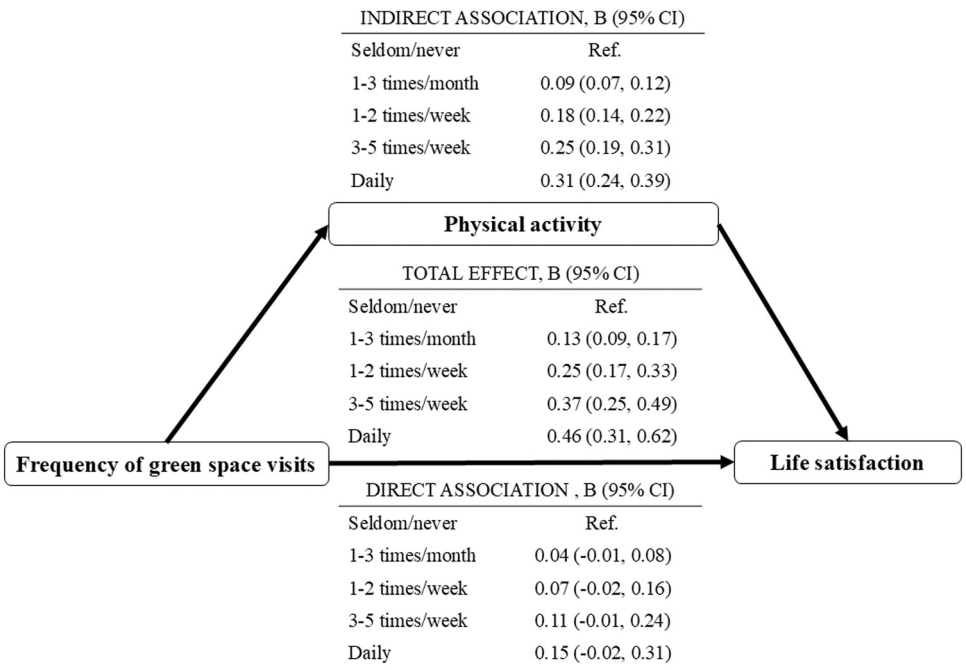

Fig. 6. Total, direct and indirect estimates for the relationship between green space visits and life satisfaction with physical social activity as the mediator (n = 5401).

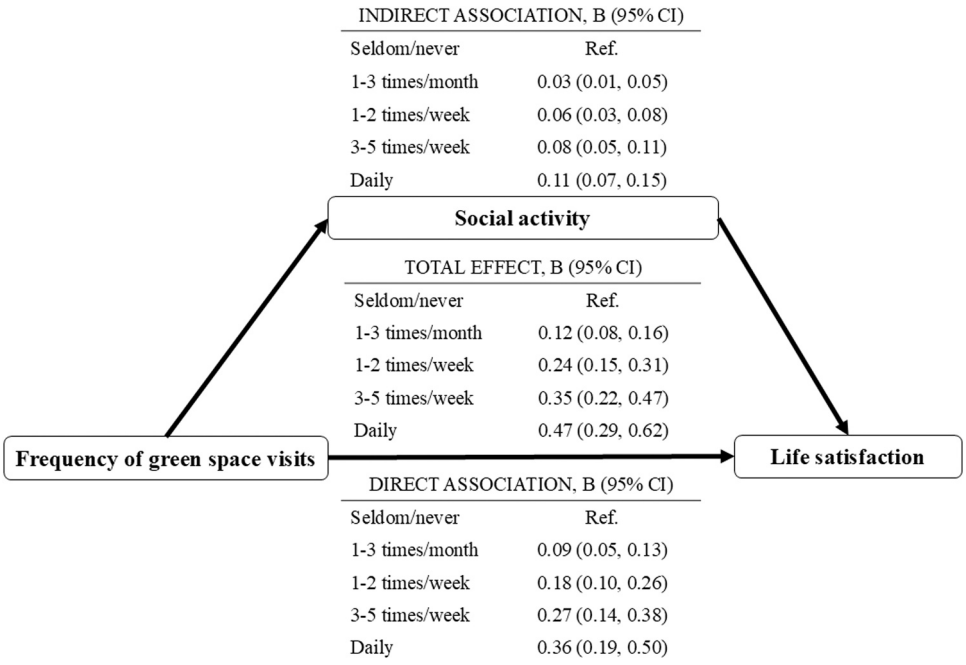

Fig. 7. Total, direct and indirect estimates for the relationship between green space visits and life satisfaction with social activity as the mediator (n = 5401).

the effect on life satisfaction depending on the frequency of green space visits. Of the total effect on the life satisfaction score (B=0.37, 95 % CI= 0.25, 0.49), an increase in the life satisfaction score by 0.25 (95 % CI= 0.19, 0.31) was attributed to physical activity for those visiting green spaces 3–5 times/week (Fig. 6). In the model with social activity as the mediator (Fig. 7), all pathways were significant. The proportion mediated by social activity varied between 23.3–23.9 % across the frequencies of green space visits. A greater proportion of the association between green space visits and life satisfaction could be attributed to participation in social activity with friends as a mediator in comparison to the model with self-perceived health as the outcome (Fig. 5). Yet only a slight increase in the life satisfaction score by 0.08 was attributed to social activity for those visiting green spaces 3–5 times/week (Fig. 7).

As for self-perceived health, the parallel mediation model showed significant total effects and non-significant direct associations between frequency of green space visits and life satisfaction (Fig. 8). Depending on green space visitation frequency, we observed that 77.0–80.5 % of the association was mediated through both physical and social activity. In this model, the indirect effects of both physical and social activity mediation were significant across all green space visitation frequencies, but the estimates were strongest for physical activity as a mediator. Compared to the single mediation models, the mediation effect was

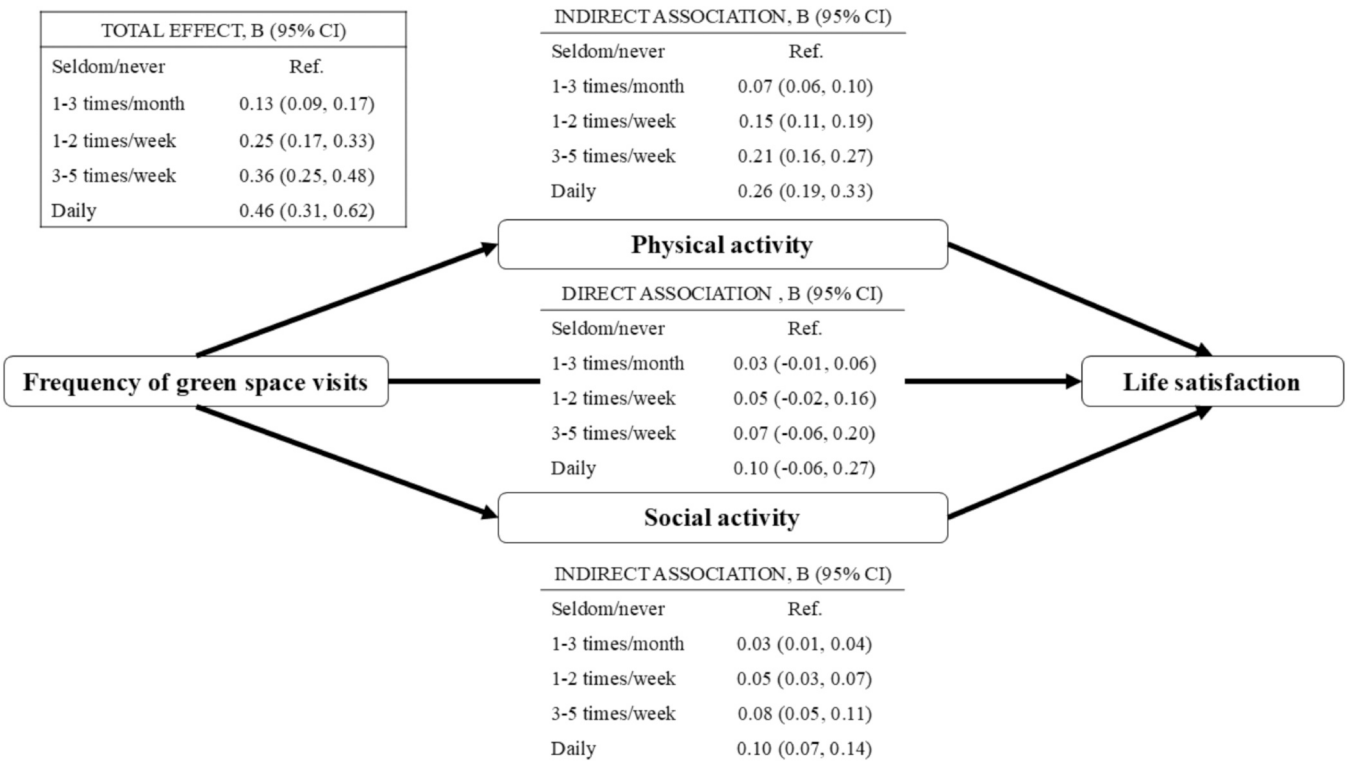

Fig. 8. Results from parallel mediation analysis with physical and social activity as mediators in the relationship between green space visits and life satisfaction.

more pronounced in the parallel model as indicated by the lower direct estimates (Fig. 8).

4. Discussion

This epidemiological study of Norwegian urban dwellers found that greater vegetation cover and good perceived access to green spaces in the neighborhood were associated with more frequent green space visits. We also found positive relationships between frequency of green space visits and the outcomes self-perceived health and life satisfaction. Both physical and social activity played roles as mediators in explaining these associations. The mediation effect was more pronounced in the parallel mediation models, with greatest indirect estimates for physical activity as a mediator.

Consistent with a substantial body of research (Browning et al., 2022; Twohig-Bennett and Jones, 2018; Yang et al., 2021), we found that more frequent green space visits were related to better self-perceived health and higher life satisfaction scores among urban dwellers. Because of the health and wellbeing benefits that contact with nature and green spaces provide, access to such health-promoting qualities in neighborhoods has been a key issue discussed in green space research for years (Haaland and van den Bosch, 2015). Studies have showed that access to green spaces in urban areas is an important predictor of green space usage (Coombes et al., 2010; Schipperijn et al., 2010; Žlender and Ward Thompson, 2017), and our study adds to this knowledge base. We found that residents residing in neighborhoods with more vegetation cover visited green spaces more frequently compared to those living in less vegetated areas. Along with the GIS-derived vegetation measure, we also analyzed data on residents' perceived access to green space. Results from these analyzes aligned with the vegetation measure by showing that good perceived access to green spaces increased the odds of more frequent green space visits. Other studies have found that residents perceive more usage constraints if they live further away from urban green spaces (Dawson et al., 2023; Misiune et al., 2021), and park visits have been reported to drop as travel distances increase (Tu et al., 2020). A higher vegetation score in the neighborhood likely indicate that the residents have access to green spaces in close vicinity to home, which could explain our results. This explanation is further supported by the great proportion of residents (87.6 %) who actually reported good access to green spaces in their neighborhoods.

Both the objective measure of vegetation cover (NDVI) and the perceived measure of access to green space were significantly related to frequency of green space visits, and the associations pointed in the same direction. The NDVI measure encompasses any vegetation present in the urban environment, including forests, parks, cemeteries, residential gardens, street trees and green corridors, while the survey assessed residents' perceived access to parks and other green spaces within the neighborhood. "Other green spaces", as formulated in the survey question, could be broadly interpreted by residents, and is likely to include green spaces captured through the NDVI. Thus, it is reasonable to assume that there is an agreement between the two measures applied, which contrasts previous studies showing clear discrepancies between objective and perceived measures of green space access (Leslie et al., 2010; Mazumdar et al., 2020; Nordh et al., 2024). Importantly, and consistent with previous studies (Fongar et al., 2019; Mantey, 2021; Neal, 2021; Orstad et al., 2017), the magnitude of our estimates was strongest for residents' perceptions of access compared to their objective access to green space. Given that consideration of resident perspectives remains a challenge in current green space planning (Haaland and van den Bosch, 2015), this aspect deserves particular attention in future studies. The practical implication of our results is that policy makers and planners must prioritize protecting and providing green infrastructure. Additionally, municipal resources are needed to ensure residents perceive they have access to green spaces, encouraging their use and visitation. This task extends beyond the role of planners alone.

In the Nordic countries, we have witnessed a noticeable shift in focus from preventing diseases to promoting health and wellbeing as an overall public health goal (Kickbusch, 2003; Raphael, 2014). A key aspiration in this respect is to create environments in which health and

wellbeing can evolve in positive directions (Stock, 2013), and our results indicate that green space visits could build capacity for public health. As already highlighted, frequency of green space visits was positively related to self-perceived health. Previous studies from other Nordic countries have also found favourable impact of green space on self-perceived health (de Jong et al., 2012; Stigsdotter et al., 2010). However, these studies measured exposure to green space in general terms and did not specifically consider whether the participants used or visited the green spaces as we did, which represent a key contribution of our study. An additional contribution of our study is the consideration of green space visitation in relation to life satisfaction. In accordance with existing research (Houlden et al., 2018), we identified a positive relationship between frequency of green space visits and life satisfaction in this sample of Norwegian urban dwellers. As such, this study follows in the series of studies that add to the substantial evidence base of the renowned benefits of green space (Browning et al., 2022; Houlden et al., 2018; Markevych et al., 2017; Marselle et al., 2021; Rojas-Rueda et al., 2019; Wolf et al., 2020; Yang et al., 2021).

What explains the identified associations between the frequency of green space visits and the two outcomes? The reasons for the apparent importance of green space visits for self-perceived health and life satisfaction warrant attention, and our study provides results that elucidate this question. Guided by existing frameworks (Markevych et al., 2017; Marselle et al., 2021), we examined green space visits as a capacity builder by assessing participation in physical and social activity as potential mediators. We found that the two variables acted as mediators in the association between green space visits and self-perceived health, as well as between green space visits and life satisfaction. Importantly, the mediation effect was enhanced in the parallel models. This means that the effect of green space visits on the two outcomes, through physical and social activity, was stronger when both mediators were included simultaneously in the mediation models. We are not aware of any studies that have used exactly the same variables and examined identical pathways, which makes it difficult to compare our findings with those of others. However, our findings align with proposed theoretical explanations (Markevych et al., 2017; Marselle et al., 2021).

Other studies that have assessed whether distance to, or the amount of, green spaces influence health and wellbeing report mixed results for both physical and social activity as mediators (Dzhambov et al., 2020). The majority of studies that contradicts our results have focused on disease outcomes (Astell-Burt et al., 2014; Dalton and Jones, 2020; O'Callaghan-Gordo et al., 2020). On the other hand, and in favor of our findings, Sugiyama et al. (2008) and Dadvand et al. (2016) identified physical activity as a mediator in relations between access to neighborhood green space and self-reported health. Sugiyama et al. (2008) also found that social cohesion partly mediated the association between neighborhood green space and mental health. This resonates well with our study, which showed that physical activity mediated a larger proportion of the associations between frequency of green space visits and the two outcomes across all models. Interestingly, the mediation effect was more pronounced in parallel mediation models, suggesting that the pathways through physical and social activity are complementary. Moreover, accounting for several factors that explain how green space visitation relates to self-perceived health and life satisfaction could lead to more robust mediation effects. This could also explain why the direct effects in the parallel mediation were non-significant, indicating that the relationship between green space visitation and the two outcomes largely is explained by engagement in physical and social activity. Other possible reasons for non-significant direct effects could include sample size and omitted variables that are important in explaining the direct associations examined (Agler and De Boeck, 2017; Rijnhart et al., 2021). Given the relatively large sample (n = 5401), it is less likely that sample size is the reason for the observed results. This suggests that omitted variables, such as income, that influence both green space visitation and the two outcomes could explain the non-significant direct effects. Additionally, the associations between green space visits and the two outcomes could not be fully explained by engagement in physical and social activity. This is not surprising considering the multiple pathways that could be involved in explaining the benefits of green space visits, such as mitigation of harm and restoration (Markevych et al., 2017; Marselle et al., 2021), which were not considered in this study.

Our study provides some new insights applicable to green space planning and management, particularly within the Nordic context. This study clearly illustrates that planners should not only care about providing green space in the urban landscape. Green spaces should also be designed and maintained with multiple functions to encourage physical activity and support social interaction, which build capacity for public health. Practical examples of such functions include trails for jogging and walking, play areas, and seating for social gatherings. This partly aligns with the concept of multifunctional green spaces, a key concept applied in research that needs more attention in practice (Hansen et al., 2019)

4.1. Strengths and weaknesses

To begin with the strengths, we analyzed data from a large number of citizens living in urban areas of Stavanger, and the survey response rate was high (45.2 %) compared to similar Norwegian health surveys (Skogen et al., 2020). A key methodological strength is that we used both NDVI and a perceived measure of access to green space. NDVI is not influenced by residents' subjective perception and the association between the amount of vegetation and green space usage is therefore not prone to single source bias (Hernán et al., 2004). However, the NDVI measure does not convey information about the quality of the vegetation or potential environmental barriers that inhibits residents to use the assessed greenery. To some extent, such aspects are included in perceived measures as quality and barriers tend to influence residents' perceptions of access (Leslie et al., 2010). Thus, the measures applied complement each other. Yet, it should be mentioned that the observed association between perceived access to green space and frequency of green space visits may be prone to common method bias (Kock et al., 2021). Another strength of the objective measure is that we utilized a commonly applied and validated index (Rhew et al., 2011) that were computed using available land cover maps from Copernicus. Lastly, the use of recently collected survey data along with our focus on self-perceived health and life satisfaction as outcomes increase the relevance of our study for current national and Nordic policies.

Several limitations of the study should also be recognized. Whilst the response rate of 45.2 % was higher than usual (Skogen et al., 2020), it is likely that our respondents were not typical of those who did not participate. When comparing the educational level of our sample with the population in Stavanger, our sample included a greater proportion of highly educated residents (47.4 % vs. 61.8 %) (Statistics Norway, 2024). Hence, selection bias is likely present. A further limitation is that the mediators, as well as both outcome measures, were based on self-reported information. This makes all these variables prone to recall and social-desirability bias due to both under- and overreporting. There are also several other weaknesses associated with the self-reported measures. First, we were not able to determine whether the reported frequency of green space visits represents actual use. Second, we only had data on weekly frequency of physical activity and were not able to assess duration, intensity and type of physical activity performed, which is recommended when assessing physical activity (Ainsworth et al., 2015). Third, the contexts in which the physical and social activity took place remain unknown. Although positive associations between green space visits and different activities were found, these pursuits could have taken place in other spaces or context than green spaces. Despite of the above-mentioned strengths of the NDVI measure, the index was computed within postal code areas, which has its limitations as it introduces measurement errors (Kwan, 2012). However, using postal code areas was the only viable option to derive an objective measure of neighborhood vegetation as the residents' addresses were not available.

Considering the mediation analyses, the models assume no unmeasured confounding to draw conclusions about direct and indirect associations (VanderWeele, 2016). Although we adjusted for several sociodemographic variables (i.e., age, gender, educational level, marital status, and ethnicity) known to influence visitation and usage of green spaces, activity participation (Beenackers et al., 2012; Schipperijn et al., 2010), as well as self-perceived health and life satisfaction (Goldblatt et al., 2023), the assumption of no unmeasured confounding may not hold as residual confounding could be possible. Finally, the cross-sectional data precluded us from stating conclusions on causality and reverse causal order cannot be ruled out. For instance, residents with good self-reported health may engage more frequently in physical and social activities, while also preferring to visit green spaces more often.

5. Conclusion

Our findings showed that a greater amount of vegetation cover and good perceived access to neighborhood green spaces were associated with more frequent green space visits among urban dwellers in Norway. Further, positive relationships between frequency of green space visits and both self-perceived health and life satisfaction were identified, and engagement in both physical and social activity played roles as intermediate factors explaining these associations. Although access to nature and green spaces are generally high in Nordic cities (Aamodt et al., 2023), our study underscores the importance of ensuring that urban dwellers have access to nearby green spaces to support more frequent green space visits. This result is particularly important to consider in urban development and construction of new residential areas. Along with previous research showing that green spaces should have restorative qualities (Dahlkvist et al., 2016; Dzhambov et al., 2018), this study has offered new evidence that green spaces should be developed with functions that support both physical and social activities as these are the pathways through which green space visits likely can build capacity for self-reported health and life satisfaction in the adult population.

Abbreviations

GIS, Geographical information systems; NDVI, Normalized Difference Vegetation Index; NIR, Near-infrared light; UN, United Nations; WHO, World Health Organization

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CRediT authorship contribution statement

Nordh Helena: Writing – review & editing, Methodology, Conceptualization. **Nordbø Emma Charlott Andersson:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2025.128777.

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