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Urban green space and mental well-being of Aotearoa New Zealand adolescents: A path analysis

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ABSTRACT

Background: Growing evidence shows the positive influence of neighbourhood green space on mental well-being among adults through multiple health behaviours, but similar studies are lacking for adolescents.

Methods: Data were drawn from the 2019 wave of the Youth2000 survey series in Aotearoa, New Zealand with secondary school students (aged 10-19 years) from the city of Tamaki Makaurau, Auckland. Emotional well-being was measured with the World Health Organization-5 Well-being Index, and depressive symptoms were assessed using the Reynolds Adolescent Depression Scale-short form. Neighbourhood green space was assessed using three different measures: percentage of green space, Normalised Difference Vegetation Index (NDVI) and the distance to nearest green space from place of residence. Exposure areas of these measures were calculated using Euclidean buffers of 100m, 300m, 800m and 1600m around participants' meshblock residential addresses. Three mediating (physical activity, social cohesion, sleep) and ten control variables (in adjusted models) were included in path analysis to test the direct and indirect relationships between green space and adolescent mental well-being.

Results: In unadjusted models, percentage of green space had a negative relationship with emotional well-being, and inconsistent effects of NDVI were detected in different buffers. Minor indirect effects of physical activity and sleep were also found. Depressive symptoms and emotional well-being were more strongly related to other individual and neighbourhood factors (e.g., neighbourhood deprivation). After adjusting for control variables, no significant associations of green space with adolescent depressive symptoms and emotional well-being were identified.

Conclusions: Urban neighbourhood green space does not appear to be a dominant factor contributing to adolescent mental well-being through physical activity, social cohesion and sleep. Appropriate individual and environmental control variables are needed to take into consideration in future studies that explore the green space-mental well-being relationships in adolescents.

Background

Adolescence is a life stage signalling transition into adulthood and is characterised by unique psychological and cognitive development which can impact mental health (World Health Organization, 2012). A large cross-sectional survey conducted in Aotearoa New Zealand (NZ) has shown adolescent emotional well-being decreased from 76% in 2012 to 69% in 2019, and depressive symptoms increased from 13% to 23% over the same time period (Fleming et al., 2020). Understanding factors that may support and promote adolescent mental well-being is therefore vital.

Urban residents' mental well-being is receiving increasing attention, with evidence suggesting high rates of mental health issues in urban environments and a range of social, economic and environmental factors at play (Ventriglio et al., 2021). One promising intervention for promoting urban adolescent's mental well-being is exposure to green space.

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Systematic reviews have revealed that increasing green space exposure could reduce the risk of depression, stress, and psychological distress; and improve mood, emotional well-being, and mental health in adolescents (Norwood et al., 2019; Vanaken & Danckaerts, 2018; Zhang et al., 2020). However, heterogeneous measurement and features of green space might have led to indistinct and sometimes contradictory findings. Furthermore, the evidence of the associations between green space and mental well-being among adolescents in NZ is largely lacking. Since the features of green space in NZ might be different from other countries (i.e., a relatively higher greenness of urban spaces (Mavoa, Lucassen, et al., 2019; Richardson et al., 2010)), exploration about whether international findings can be transferred to the NZ context are required.

Recent evidence also indicates various possible pathways between green space and mental health (Hartig et al., 2014; Markevych et al., 2017; World Health Organization, 2016). Green space could reduce harmful exposures such as noise and air pollution in the neighbourhood; and enhance psychological restoration, physical activity, social cohesion and sleep, which in turn might lead to better mental well-being. However, these pathways have been examined mainly in the adult population. Studies that focus on adolescents in this field remain scarce. Given the unique life stage of adolescence, it is possible that associations between green space and mental well-being differ from the adult population, through physiological pathways and through different behaviours and exposures. Thus, there is a need to understand the pathways between green space and adolescent mental health, considering potential mediating effects and carefully adjusting for factors of importance that might impact these relationships.

Three potential mediators in the relationship between green space and adolescent mental well-being have been suggested: physical activity (PA), social cohesion and sleep. PA contributes to mental well-being and has been proposed as a potential mediator in the relationship between green space and mental well-being outcomes (Dzhambov, 2018; Dzhambov et al., 2018; Qin et al., 2021; Wang, Helbich, et al., 2019; Zhang et al., 2018). Empirical evidence suggested that green space could promote PA (Zhang et al., 2019) which simultaneously contributes to mental well-being (Dzhambov, 2018; Dzhambov et al., 2018; Qin et al., 2021; Wang, Helbich, et al., 2019; Zhang et al., 2018). For instance, the time spent in, and the proximity of green space to the residence was positively related to increased PA levels (An et al., 2019; Ward et al., 2016). PA frequency has been associated with the level of greenness and availability of green space (Akpınar, 2020; Bloemsma et al., 2018). Duration of PA has been associated with sports facilities and green space design (Akpınar, 2020). Alternatively, undertaking PA in green space might provide more mental health benefits than activity indoors (Thompson Coon et al., 2011). Inconsistent results have been found, with some green space and mental health research failing to detect indirect effects of PA in both adults (de Vries et al., 2013; Dzhambov et al., 2018; Maas et al., 2008; Triguero-Mas et al., 2015) and adolescents (Herrera et al., 2018).

Social cohesion has been examined across multiple studies in adult populations (Gascon et al., 2018; Gascon et al., 2015; Zhang et al., 2021). Green space exposure was found to increase social interaction and enhance a sense of community, which may positively affect mental well-being (Jennings & Bamkole, 2019; World Health Organization, 2016). However, mixed findings with significant results have been reported in some studies (Qin et al., 2021; Wang, Helbich, et al., 2019; Yang et al., 2020), while others reported no indirect effects (Dzhambov et al., 2018; Dzhambov et al., 2018; Triguero-Mas et al., 2017; Wang, Meng, et al., 2019).

Adequate sleep is also known to be important for adolescents' mental health (Short et al., 2020). Sleep deprivation on school evenings is a global occurrence, with adolescents' bedtimes postponing as they grow. Even with later bedtimes, school starts at the same time every day, resulting in inadequate sleep duration over the school week (Bartel et al., 2015). A recent study suggests that a higher neighbourhood tree canopy cover was associated with earlier sleep timing in adolescents. The finding hints towards a function for green space in protecting residents from adverse effects (i.e., light, noise and temperature) while sleeping (Mayne et al., 2021). However, the potential indirect effect of sleep in the relationship between green space and mental well-being is a relatively new consideration, and predominantly explored in the adult population. Green space exposure could improve sleep by providing sufficient natural daylight exposure, which might link to positive mental health outcomes (Shin et al., 2020; World Health Organization, 2016). Exposure to daylight is important to sleep quality and quantity (Aries et al., 2015). Evidence suggests that a higher level of green space exposure was associated with facilitating sleep quality (Bodin et al., 2015; Grigsby-Toussaint et al., 2015) and increasing sleep duration (Astell-Burt et al., 2013; Johnson et al., 2018) in adults, but significant associations were not found in other research (Chum et al., 2015; Feng et al., 2020; Johnson et al., 2018).

It remains unclear how green space is linked to mental well-being through these mediators. Path analysis, which is a special case of structural equation modelling without latent variables, is a useful multivariate method for testing the mediated relationships between variables. The strength of path analysis is the capacity to test the direct and indirect effects among multiple variables simultaneously (Barbeau et al., 2019).

Some studies (Liu, Wang, Grekousis, et al., 2019; Liu, Wang, et al., 2020; Zhang et al., 2018) conducted structural equation modelling using single and parallel pathways and the others (Dzhambov et al., 2018; Yang et al., 2020) used serial pathways to test the mechanisms underlying the association between green space and mental well-being in adults. These studies showed that PA and social cohesion at least partially mediated the relationship between green space and mental well-being. However, these studies focused on adults and did not consider the mediatory role of sleep.

As highlighted by the systematic reviews (Vanaken & Danckaerts, 2018; Zhang et al., 2020), few studies have explored plausible mediators in the green space and mental well-being associations in adolescents, where multiple mediators were seldom included simultaneously and the mediatory role of sleep has never been considered. Due to this lack of empirical evidence on potential mediators between green space and mental well-being in adolescents, further research of these indirect effects is needed (Dzhambov et al., 2018; Wang, Meng, et al., 2019). For example, a recent study to explore the association between green space and adolescents' mental well-being in the USA showed a null relationship (Hartley et al., 2021). In contrast, a significant relationship between reduced depressive symptoms and higher level of Normalized Difference Vegetation Index (NDVI) was found among adolescents in NZ (Mavoa, Lucassen, et al., 2019). However, indirect effects in these associations were not examined in these two studies.

Research aim

In light of the research gaps presented as well as limited evidence in the context of NZ (e.g., Mavoa, Lucassen, et al. (2019)), this research aims to assess the relationship between green space and mental well-being with multiple pathways among adolescents living in urban NZ using path analysis.

Conceptual model

The conceptual model is presented in Fig. 1. We examined the associations between three green space indicators (percentage of green space, NDVI, distance to nearest green space), three mediators (PA, social cohesion, sleep), and two mental well-being outcomes (depressive symptoms, emotional well-being). Based on the existing literature, we hypothesized that (1) depressive symptoms would negatively relate to three mediators and three green space indicators; and (2) emotional well-being would positively relate to three mediators and three green

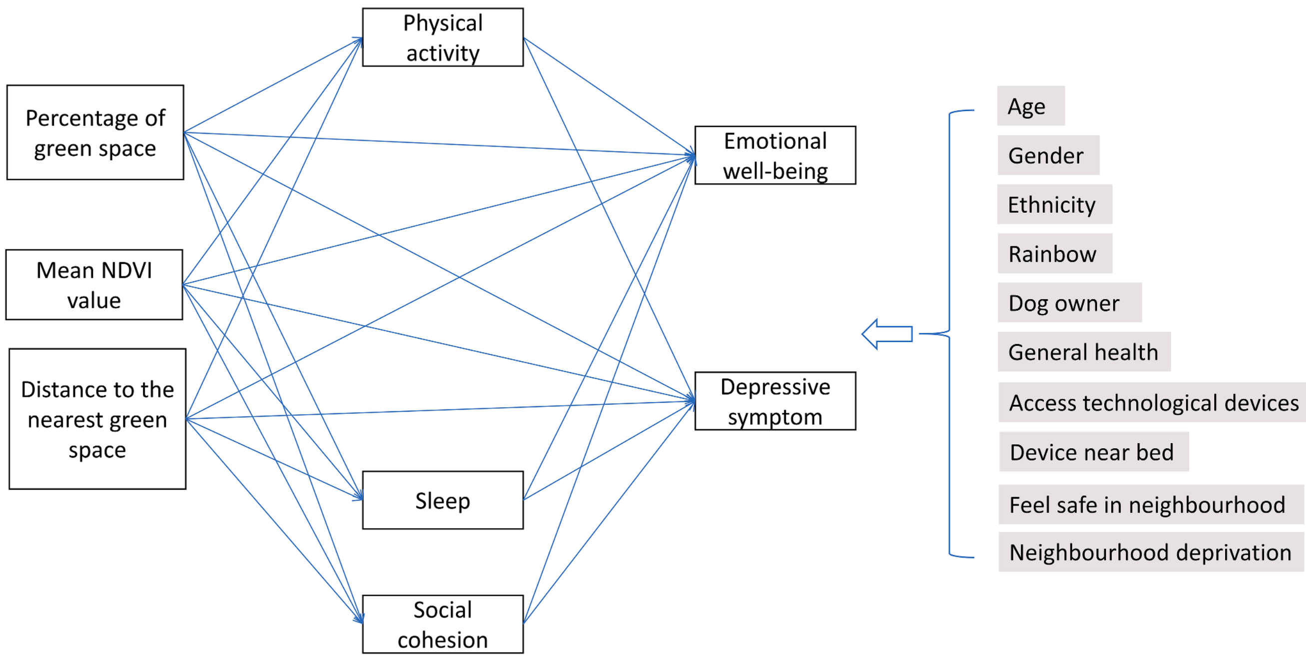

Fig. 1. Conceptual model of the pathway between green space and mental well-being for adolescents in NZ.

space indicators. We further hypothesized that three green space indicators would be indirectly linked to two mental well-being outcomes via three mediators where three green space indicators have positive relationships with three mediators (see additional file 1). Ten control variables were included based on previous relevant research: gender; age; ethnicity; neighbourhood deprivation (Hartley et al., 2021); rainbow group (at least one of gender diverse, attracted to same sex or sexual orientation outside of straight/mostly straight) (Adams et al., 2013); general health (Wang, Meng, et al., 2019); dog ownership (Li et al., 2018); feeling safe in the neighbourhood (Mueller et al., 2019); access to technological devices; and presence of a device near bed (Li et al., 2018).

Methods

Study area

The current study area was Tāmaki Makaurau/Auckland (hereafter Tāmaki Makaurau), NZ. Tāmaki Makaurau is NZ's largest city with a population of 1.57 million (33% of the total population) in 2018, with approximately 94% residing in urban areas (Statistics New Zealand, 2018). Tāmaki Makaurau's population is younger than the national average – in 2018, 26.1% of the population were adolescents aged 10-19 years (Malone & Rudner, 2011). The city has considerable ethnic diversity, and the total population is made up of 11.5% Māori, 15.5% Pacific, and 28.2% Asian ethnicities (Statistics New Zealand, 2018). Tāmaki Makaurau's young, diverse, and highly urbanised population make the city an ideal setting for exploring environmental associations of mental well-being in urban-dwelling adolescents.

Protocol

This study draws data from the cross-sectional Youth19 Rangatahi Smart Survey (Youth19), which is the latest in the Youth2000 series of NZ adolescent health and well-being surveys (Fleming et al., 2020). Youth19 was conducted across secondary schools (NZ high school year 9-13, age range 12-19 years) in the Tāmaki Makaurau, Northland, and Waikato regions of NZ in terms two and three (April 29 to September 27), 2019. School representatives provided informed consent for their school to participate. Parents/caregivers were provided with study information sheets from their school and given two weeks to opt their children out of the survey. Students were randomly selected for invitation and provided information sheets and consent forms. Students could choose to opt out from the survey on the day of data collection.

The survey was anonymous, students entered their usual place of residence into a custom web app that resolved and saved their 2018 census meshblock code without storing their home address. Meshblocks are Statistics NZ's smallest geographic unit for statistical data. The size of a meshblock varies from part of a city block to vast areas of rural land, optimally containing 30 – 60 dwellings, and a maximum of 120 dwellings (Statistics New Zealand, 2016). Ethical approval was granted by the University of Auckland Human Subjects Ethics Committee (No. 022244). Only data from the Tāmaki Makaurau region were extracted for analysis in the current study.

Measures

Mental well-being outcomes

Adolescent emotional well-being was assessed using the World Health Organization-5 Well-being Index (WHO-5) (Bech et al., 2003). The WHO-5 consists of five items, and each scored on a 5-point Likert scale ranging from 'at no time (0)' to 'most of the time (5)'. Scores from the five items were summed where a higher score indicated greater emotional well-being.

Depressive symptoms were measured using the Reynolds Adolescent Depression Scale-short form (RADS-SF), which asked participants to rate their usual feelings using ten different statements on a scale from 'never (1)' to 'most of the time (4)'. Scores from the ten items were summed where a higher score indicated greater depressive symptoms. The RADS-SF had high internal reliability (Cronbach's alpha = 0.88) and was strongly correlated (r = 0.95) to the RADS in NZ adolescents (Milfont et al., 2008).

Green space exposure

Exposure areas were calculated using Euclidean buffers of 100m, 300m, 800m and 1600m for participant's residential meshblocks. Conventionally, area-level buffers are drawn around either centroids or boundaries of areas using a certain Euclidian or network distance

(Mavoa, Lucassen, et al., 2019). In this study, we developed a new method by buffering around all residential addresses within a meshblock and then merging them into one meshblock residential street address buffer. This buffer provides a more accurate representation of residents' exposure to green space, because all green space in proximity to a residential address is included. Other methods, such as buffering around a population weighted centroid may exclude green space in some residents' exposure area, as shown in Fig. 2. Alternatives such as buffering around the meshblock boundary may include green space that is not proximate to a residential address. We used two urban meshblocks in Tāmaki Makaurau in Fig. 2 to illustrate the advantages of buffering around residential addresses in a meshblock where the addresses are not evenly distributed, which is a common occurrence in urban areas.

Three green space measures commonly used in green space-mental health research (Dzhambov et al., 2018; Mavoa, Bagheri, et al., 2019) were calculated using geographic information systems (GIS): (1) surrounding greenness for each meshblock residential address buffer, (2) the proportion of green space included in each meshblock residential address buffer, and (3) mean Euclidean distance from each residential address to the boundary of its nearest green space.

Surrounding greenness was estimated using NDVI, a proxy of levels of greenness which ranges from -1 to +1, based on the red wavelength absorption and the infrared light reflection of vegetation. Values closer to +1 generally represent highly vegetated surfaces (Emerson et al., 1999). We used Google Earth Engine to calculate NDVI using a custom script (Ramsey & Mavoa, 2021) to extract a time-series of Sentinel-2 satellite images at a resolution of 10m x 10m for April 29 to December 18, 2019. The end-date presented here differs slightly from that for the survey was due to practical reasons. It is worth noting it is unlikely that this short time period would have had a significant impact on levels of vegetation. Generally, Tamaki Makaurau has warm and humid summers and mild winters. Differences between seasons are comparatively low, with the region having rainfall throughout the year and a mean daily temperature range of 7.9 °C (Chappell, 2014). For each pixel in the time series, the median cloud-free NDVI value was extracted. NDVI data less than zero were removed to ensure that the greenness calculation did not include elements such as water or moist soil (Gascon et al., 2018; Mavoa, Lucassen, et al., 2019). Mean NDVI values within a buffer were calculated using QGIS software (QGIS Development Team, 2018) to represent surrounding greenness.

The percentage of neighbourhood green space and the mean distance to the edge of the nearest urban green space was calculated based on 2019 Open Street Map data (*Open Street Map data for New Zealand*, 2019). Seven types of urban green space were included: "allotments", "meadow", "natural reserve", "grass", "park", "scrub" and "forest". The distance scores were reverse coded where higher scores indicated shorter distance.

Mediators

Three mediators are outlined in Table 1. PA was quantified by the self-reported frequency of physical activity multiplied by the self-reported duration of physical activity (in the last episode). Social cohesion was derived from the summed score of two questions focusing on participants' interaction with communities, which tapped into participants' willingness to join in a group and care for others. Sleep was classified into a 5-level item using reported time of going to bed.

Control variables

Ten evidence-based control variables were included: gender (female; male; identify in another way), age (in years), ethnicity (European; Asian; Māori; Pacific), rainbow group (yes; no), neighbourhood deprivation (high; median; low), general health (5-level Likert scale), dog owner (yes, a dog; yes, other animals; no), feeling safe in the neighbourhood (4-level Likert scale), access to technological devices (yes; no), and presence of device near bed (yes; no).

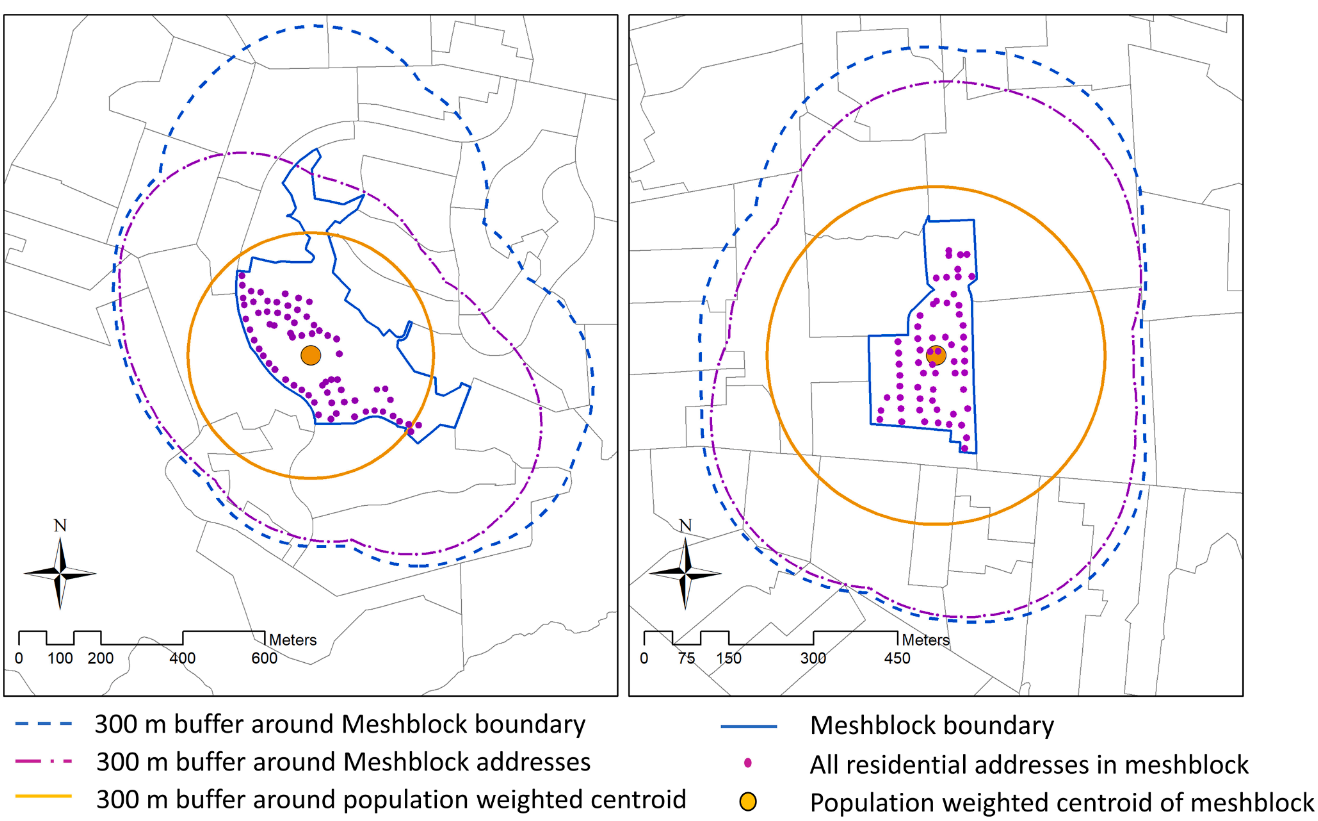

Fig. 2. The comparison of buffers

Table 1
Information about observed variables and their descriptive statistics (N = 2174)

Observed variable	Description	Data source	Variable type	Measurement scale	Descriptive statistics
Green space indicators					
Distance to the nearest green space	Straight-line distance to the edge of the nearest green space	Open street map	Continuous	—	160.23 ± 104.18
Buffer size: 100m					
Mean NDVI	Average of greenness in the neighbourhood	Sentinel-2	Continuous	—	0.48 ± 0.08
Percentage of green areas	Percentage of green space in the neighbourhood	Open street map	Continuous	—	6.54 ± 9.80
Buffer size: 300m					
Mean NDVI	Average of greenness in the neighbourhood	Sentinel-2	Continuous	—	0.48 ± 0.08
Percentage of green areas	Percentage of green space in the neighbourhood	Open street map	Continuous	—	9.40 ± 9.82
Buffer size: 800m					
Mean NDVI	Average of greenness in the neighbourhood	Sentinel-2	Continuous	—	0.47 ± 8.25
Percentage of green areas	Percentage of green space in the neighbourhood	Open street map	Continuous	—	11.61 ± 0.08
Buffer size: 1600m					
Mean NDVI	Average of greenness in the neighbourhood	Sentinel-2	Continuous	—	0.45 ± 0.09
Percentage of green areas	Percentage of green space in the neighbourhood	Open street map	Continuous	—	11.89 ± 6.75
Physical activity	Frequency of exercise x duration		Continuous		159.77 ± 129.52
Frequency of exercise	In the last 7 days, how many times have you done any exercise or activity that makes you sweat or breathe hard, or gets your heart rate up (such as soccer or rugby, running, swimming laps, fast bicycling etc.)?	Youth'19	Ordinal	0 = I don't exercise/ Not in the last 7 days	10.4%
				2 = 1 - 3 times	43.6%
				5 = 4 - 6 times	30.6%
				7 = 7 or more times	15.4%
Duration of last episode of exercise	The last time you did this how long did you do this physical activity for?		Ordinal	10 = Up to 10 minutes	5.2%
				15 = 11-20 minutes	9.6%
				25 = 21-30 minutes	16.0%
				45 = 31-60 minutes	32.6%
				60 = More than 60 minutes	36.8%
Social cohesion	Summed scores of 2 items		Continuous		1.31 ± 0.67
Belonging to a group outside of school	Are you belong to the following group, (1) sports team or group, (2)A cultural group, (3) A diversity group that supports sexuality and gender diverse youth, gay/straight alliance, or rainbow group, (4) Another type of group or club, e.g., music, drama, gaming?	Youth'19	Binary	0 = No	18.6%
				1 = Yes	81.4%
Time spent helping others in community	Do you give your time to help others in your school or community (e.g., as a peer supporter at school, help out on the Marae or church, help coach a team or belong to a volunteer organisation)?		Ordinal	0 = No	45.2%
				0.5 = I don't know	10.7%
				1 = Yes	44.1%
Sleep					
Time going to sleep	What time do you go to sleep on a school night?	Youth'19	Continuous	1 = After midnight	6.0%
				2 = Between 11pm - 12am	18.8%
				3 = Between 10pm - 11pm	34.1%
				4 = Between 9pm - 10pm	33.7%
				5 = Before 9pm	7.4%
Mental well-being outcomes					
WHO-5 Well-being Index	Summed scores of 5 items	Youth'19	Continuous		15.95 ± 5.35
				1 = All of the time	
	I have felt cheerful and in good spirits			2 = Most of the time	
	I have felt calm and relaxed			3 = More than half of the time	
	I have felt active and vigorous			4 = Less than half of the time	
	I woke up feeling fresh and rested			5 = Some of the time	
	My daily life has been filled with things that interest me			6 = At no time	
Reynolds Adolescent Depression Scale (RADS)	Summed scores of 10 items	Youth'19	Continuous		21.85 ± 5.96
Control variables					
Dog owner	Do you have a pet?	Youth'19	Nominal	0 = no	44.3%
				1 = Yes, others	25.9%
				2 = Yes, dog	29.8%

(*continued on next page*)

Table 1 (*continued*)

Year	How old are you?	Youth'19	Continuous	1 = Under 12 years	0.0%
				2 = 12	0.3%
				3 = 13	18.4%
				4 = 14	25.7%
				5 = 15	22.0%
				6 = 16	17.4%
				7 = 17	12.9%
				8 = 18	2.9%
				9 = 19	0.2%
				10 = Over 19 years	0.0%
Gender	Participants' gender	Youth'19	Nominal	0 = Female	65.8%
				1 = Male	33.7%
				2 = Identify in another way	0.6%
Ethnicity	Participants' ethnicity	Youth'19	Binary*	0 =NZ European/ Māori/Pacific/other	68.2%
				1 = Asian	31.8%
			Binary*	0 = Māori/Pacific/ Asian/other	63.5%
				1 = NZ European	36.5%
			Binary*	0 = NZ European/ Pacific/Asian/other	90.2%
				1 = Māori	9.8%
			Binary*	0 = NZ European/ Māori/Asian/other	82.9%
				1 = Pacific	17.1%
Rainbow group	Participants as Rainbow	Youth'19	Binary	0 = no	91.9%
				1 = yes	8.1%
Neighbourhood deprivation	Participants' neighbourhood deprivation	Youth'19	Ordinal	1 = high	26.2%
				2 = median	39.1%
				3 = low	34.6%
Feel safe in the neighbourhood	Do you feel safe in your neighbourhood?	Youth'19	Ordinal	1 = Never	2.0%
				2 = Not often	2.7%
				3 = Sometimes	38.4%
				4 = All the time	56.9%
Overall health	In general, how would you say your health is?	Youth'19	Continuous	1 = Poor	0.5%
				2 = Fair	4.4%
				3 = Good	21.8%
				4 = Very good	46.8%
				5 = Excellent	26.5%
Access technological devices	Do you have access to a smartphone, laptop, tablet or iPad, Chromebook or desktop computer that you can use in your spare time?	Youth'19	Binary	1 = Yes	98.7%
				2 = No	1.3%
Device near bed	When you go to sleep at night, do you have a smartphone or other device that can go online within reach (close enough that you can reach it without getting out of bed?)	Youth'19	Binary	1 = Yes	73.5%
				2 = No	26.5%

Note: Frequencies (%) for binary or ordinal variables; mean ± standard deviation for continuous variables.

Sample

In total, 7721 students from 49 secondary schools completed surveys. Recognising the presence of health conditions might influence mental well-being outcomes, we excluded adolescents who had long-term health conditions or disability from the current analyses with the intention of conducting separate analyses for this population group. Disabled children and young people have lower levels of physical activity participation and mobility compared with their non-disabled peers (Murphy et al., 2008), including in NZ (Statistics New Zealand, 2013). Previous research in NZ has highlighted the inequitable opportunities for participation and mobility due to ableist social and physical structures, which extend to limited opportunities to experience and benefit from natural settings (Smith, Calder-Dawe, et al., 2021). Accordingly, we hypothesized that the pathways from green space to mental well-being may differ in meaningful ways between participants who did or who did not report long-term health conditions or disability. We also excluded adolescents who had no meshblock information or resided in a rural area as defined by Statistics NZ's Urban Rural definition (Statistics New Zealand, 2021). Participants outside the Tāmaki Makaurau region were excluded. Participants with missing values were deleted because the data were missing completely at random (Chi-Square = 7.733, degree of freedom = 5, p = 0.172). In total, an analytic sample of 2174 adolescents were included in the current analyses (Fig. 3).

Statistical analysis

Descriptive analyses were conducted using SPSS version 25.0. Path analysis was performed using Mplus 8.3 software (Muthén & Muthén, 2017). Maximum likelihood estimation was used to analyse the continuous, categorical and non-normally distributed variables (Kline, 2015). Path analysis was used to investigate direct and indirect effects among a set of observed endogenous and exogenous variables simultaneously (Barbeau et al., 2019). As illustrated in Fig. 1, the main path model was created by regressing depressive symptoms and emotional well-being on PA, social cohesion, sleep and three green space indicators simultaneously. The ten control variables were included as additional predictors in all regression equations. Fully saturated (i.e., zero degrees of freedom) models were used to test for indirect effects of each green space indicator on depressive symptoms and emotional well-being through three mediators. Since fully saturated models always fit the data perfectly (Kline, 2015), model fit indices were not reported.

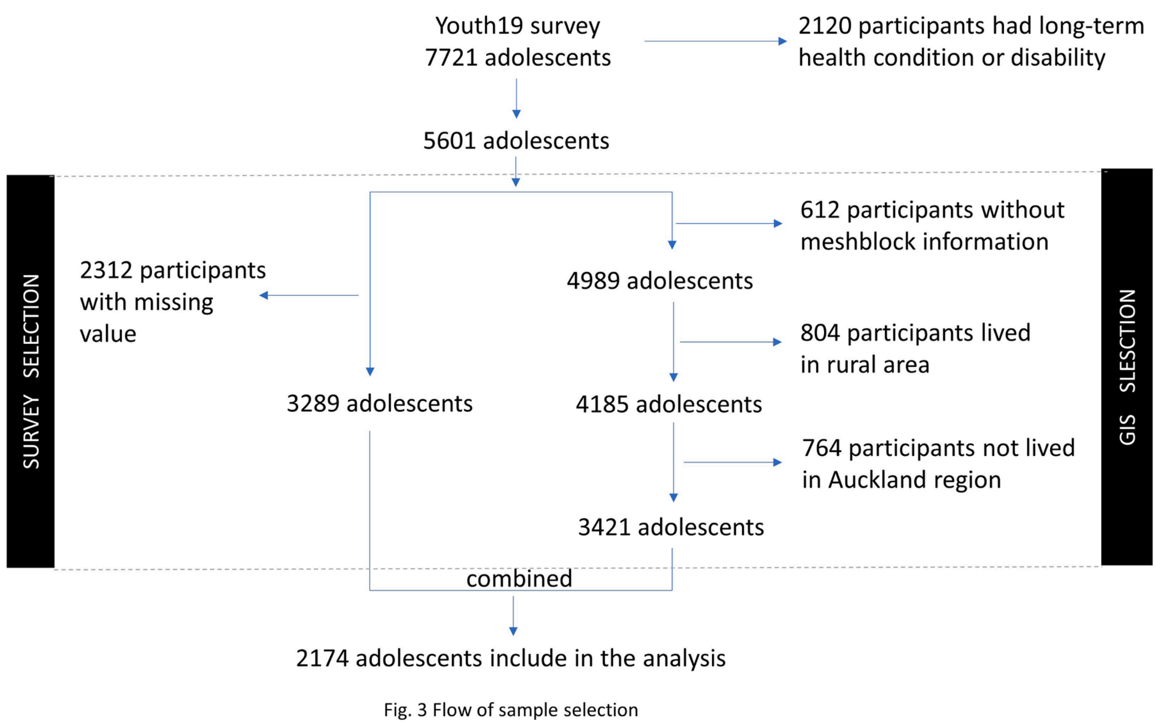

Fig. 3. Flow of sample selection

Bootstrap samples (n=1000) and 95% bias-corrected confidence intervals were employed to detect the significance of indirect effects of PA, social interaction and sleep. Significance level was set at 5%.

Results

Descriptive statistics

Most participants ranged in age from 13 to 18 (95%), about 65.8% were female and 8% were rainbow group. The characteristics of 2174 participants included in the analyses and the percentage of green space, NDVI values, and distance to the nearest green space are presented in Table 1.

Path analysis

Results of unadjusted path models are shown in Table 2 (for full results see additional file 2). The unadjusted path models of four buffer sizes explained 6.2%-6.3% of variance in depressive symptoms and 9.3%-9.7% of variance in emotional well-being. There was a significant positive path from NDVI to emotional well-being in the 1600m buffer (estimate = 0.081, $p < 0.001$). In contrast, a negative association between NDVI and emotional well-being was observed in the 100m buffer (estimate = -0.050, $p < 0.05$). A significant negative relationship between the percentage of green space and emotional well-being was found in the 1600m buffer (estimate = -0.051, $p < 0.05$). A non-significant direct effect of three green space indicators on depressive symptoms was found in all four buffer sizes.

In terms of the mediators, NDVI were positively related to PA (estimate = 0.083, $p < 0.001$) in the 100m buffer, and to sleep in the 100m (estimate = 0.087, $p < 0.001$) and 300m buffers (estimate = 0.057, $p < 0.05$). PA and sleep were significantly associated with both depressive symptoms and emotional well-being in the expected direction across all buffers. The relationships between social cohesion, green space indicators and mental well-being outcomes were not statistically significant.

Results of adjusted models are presented in Table 3 (for full results see additional file 3). The fully adjusted models explained 24.2%-24.3% of variance in depressive symptoms and 27.5%-27.6% of variance in emotional well-being. After adjusting for all control variables, the associations between green space indicators, mental well-being and mediators were no longer significant. However, the relationships between sleep and depressive symptoms stayed negative, and those between three mediators and emotional well-being remained positive in the adjusted analyses.

Mediation analysis

Mediation analysis showed that in the unadjusted model, the indirect effects of NDVI on depressive symptoms and emotional well-being through sleep in four buffer sizes were significant but negligible (Additional file 4). PA mediated the association of NDVI and emotional well-being and depressive symptoms respectively in the 100m buffer. No indirect effects were found in the fully adjusted model (Additional file 5).

Discussion

This study examined the relationships between green space exposure and adolescent mental well-being through multiple pathways. To our knowledge, this is the first study which used path analysis to test the indirect effects of PA, social cohesion, and sleep on the associations between green space and mental well-being simultaneously among adolescents. The findings suggest that neighbourhood green space was not strongly related to adolescent depressive symptoms or emotional well-being in a large NZ urban setting. However, direct effects of NDVI and percentage of green space as well as minor indirect effects of PA and sleep were detected before adding control variables. The evidence base is mixed, with some studies reporting null results for the mental well-being outcomes of green space for adolescents (Hartley et al., 2021; Huynh et al., 2013; Mueller et al., 2019; Srugo et al., 2019) and others demonstrating significant relationships (Bezold et al., 2018; Feda et al., 2015), including in Tāmaki Makaurau, NZ (Mavoa, Lucassen, et al., 2019). No mediation analysis was performed in these studies, therefore we were unable to make direct comparisons between their findings and

Table 2
Results of unadjusted path models showing the effects of green space exposures on emotional well-being and depressive symptoms.

Buffer	Variables	RADS-SF Estimate (BC 95% CI)	WHO-5 Estimate (BC 95% CI)
100m			
	Physical Activity	-0.148 (-0.875, -0.470) ***	0.193 (0.625, 0.961) ***
	Social Cohesion	-0.014 (-0.492, 0.242)	0.028 (-0.108, 0.572)
	Sleep	-0.177 (-1.290, -0.804)	0.207 (0.853, 1.312) ***
	Percentage	-0.004 (-0.351, 0.333) ***	-0.013 (-0.355, 0.222)
	NDVI	0.000 (-0.291, 0.286)	-0.050 (-0.522, -0.029) *
	Distance (inverse)	0.013 (-4.661, 0.261)	0.009 (-0.018, 3.750)
300m			
	Physical Activity	-0.148 (-0.876, -0.474) ***	0.191 (0.618, 0.955) ***
	Social Cohesion	-0.014 (-0.491, 0.242)	0.027 (-0.109, 0.566)
	Sleep	-0.177 (-1.292, -0.802) ***	0.206 (0.852, 1.305) ***
	Percentage	0.015 (-0.262, 0.427)	-0.046 (-0.513, 0.020)
	NDVI	-0.008 (-0.347, 0.232)	-0.027 (-0.395, 0.106)
	Distance (inverse)	0.009 (-4.171, 0.126)	0.012 (0.008, 3.110)
800m			
	Physical Activity	-0.148 (-0.878, -0.476) ***	0.189 (0.612, 0.946) ***
	Social Cohesion	-0.014 (-0.497, 0.243)	0.027 (-0.111, 0.569)
	Sleep	-0.177 (-1.293, -0.803) ***	0.203 (0.836, 1.296) ***
	Percentage	0.013 (-0.250, 0.374)	-0.044 (-0.480, 0.006)
	NDVI	-0.022 (-0.408, 0.146)	0.032 (-0.076, 0.420)
	Distance (inverse)	0.011 (-2.505, 0.291)	0.007 (-2.293, 0.947)
1600m			
	Physical Activity	-0.148 (-0.880, -0.477) ***	0.191 (0.615, 0.946) ***
	Social Cohesion	-0.014 (-0.501, 0.242)	0.029 (-0.094, 0.584)
	Sleep	-0.178 (-1.301, -0.813) ***	0.206 (0.849, 1.310) ***
	Percentage	-0.012 (-0.378, 0.229)	-0.051 (-0.508, -0.023) *
	NDVI	-0.011 (-0.336, 0.253)	0.081 (0.172, 0.670) **
	Distance (inverse)	0.015 (-2.443, 0.941)	0.005 (-2.348, 1.069)

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; BC, bias corrected; 1,000 bootstrap samples; RADS-SF, Reynolds Adolescent Depression Scale-short form; WHO-5, World Health Organization-5 Well-being Index; NDVI, Normalised Difference Vegetation Index

Table 3
Results of the fully adjusted path model showing the effects of green space exposures on emotional well-being and depressive symptoms.

Buffer	Variables	RADS-SF Estimate (BC 95% CI)	WHO-5 Estimate (BC 95% CI)
100m			
	Physical Activity	-0.029 (-0.307, 0.083)	0.097 (0.235, 0.555) ***
	Social Cohesion	-0.019 (-0.526, 0.191)	0.044 (0.052, 0.673) ***
	Sleep	-0.112 (-0.942, -0.391) ***	0.148 (0.543, 1.001) ***
	Percentage	-0.013 (-0.378, 0.286)	0.001 (-0.273, 0.244)
	NDVI	0.025 (-0.120, 0.400)	-0.043 (-0.450, 0.009)
	Distance (inverse)	0.017 (-3.827, 0.177)	0.008 (-0.230, 2.771)
300m			
	Physical Activity	-0.029 (-0.308, 0.082)	0.097 (0.234, 0.557) ***
	Social Cohesion	-0.018 (-0.538, 0.191)	0.044 (0.049, 0.669) *
	Sleep	-0.112 (-0.939, -0.388) ***	0.148 (0.543, 1.004) ***
	Percentage	0.002 (-0.300, 0.322)	-0.023 (-0.371, 0.106)
	NDVI	0.009 (-0.243, 0.317)	-0.028 (-0.364, 0.077)
	Distance (inverse)	0.015 (-3.001, 0.153)	0.011 (-0.708, 1.873)
800m			
	Physical Activity	-0.029 (-0.306, 0.087)	0.097 (0.232, 0.556) ***
	Social Cohesion	-0.018 (-0.533, 0.193)	0.044 (0.042, 0.665) *
	Sleep	-0.111 (-0.934, -0.381) ***	0.146 (0.532, 0.996) ***
	Percentage	-0.001 (-0.285, 0.277)	-0.009 (-0.264, 0.193)
	NDVI	-0.011 (-0.348, 0.182)	0.004 (-0.204, 0.244)
	Distance (inverse)	0.017 (-1.654, 0.479)	0.006 (-1.781, 1.268)
1600m			
	Physical Activity	-0.029 (-0.308, 0.085)	0.097 (0.228, 0.553) ***
	Social Cohesion	-0.018 (-0.535, 0.196)	0.044 (0.048, 0.668) *
	Sleep	-0.112 (-0.938, -0.385) ***	0.146 (0.531, 0.996) ***
	Percentage	-0.026 (-0.445, 0.128)	-0.006 (-0.245, 0.203)
	NDVI	-0.011 (-0.337, 0.248)	0.032 (-0.077, 0.423)
	Distance (inverse)	0.021 (-1.448, 0.800)	0.003 (-1.823, 0.968)

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; BC, bias corrected; 1,000 bootstrap samples; RADS-SF, Reynolds Adolescent Depression Scale-short form; WHO-5, World Health Organization-5 Well-being Index; NDVI, Normalised Difference Vegetation Index

ours.

Green space

There are several possible reasons for the null results of fully adjusted models. Firstly, the control variables had greater impacts on mental well-being than green space. Several control variables across individual and neighbourhood factors were associated with depressive symptoms and emotional well-being in this study (see additional file 5), for the most part aligning with previous research (Fleming et al., 2020; Liu, Powell, et al., 2019; Roy et al., 2021; Visser et al., 2021). A systematic review identified a lack of consideration of control variables when examining relationships between environments and adolescent mental well-being (Zhang et al., 2020). Findings from this study illustrated the importance of carefully considering the inclusion of appropriate individual and environmental control variables in future research.

Secondly, it is possible the measures that we used were not adequate to represent relevant variables. In parallel with previous studies with adults (Banay et al., 2019; Liu, Wang, Grekousis, et al., 2019; Liu, Wang, et al., 2020; Liu, Wang, Xiao, et al., 2019; Qin et al., 2021; Wang, Meng, et al., 2019), findings suggest that NDVI and the percentage of green space directly affect adolescent mental well-being. There are several possible reasons for the negative and inconsistent relationships including imbalance of green space supply and demand. For example, there may be geographic variance in green space availability and access as well as population density by urbanicity (e.g., comparing city centre versus suburban areas) (Liu, Remme, et al., 2020). Types, quality and variation of green space may also be important factors. For example, in adults (Akpinar et al., 2016) and adolescents (Wallner et al., 2018), forests were associated with fewer days of mental health complaints and maintaining adolescent mood stability between school classes than other green space types. Adolescent mental well-being has been linked with higher green space quality, but not the percentage of neighbourhood green space in an Australian study (Feng & Astell-Burt, 2017). Higher NDVI might represent an aspect of the quality of green space, which refers to healthy vegetation. Our findings suggest greener spaces using 1600m buffers could support adolescent mental well-being, while a negative relationship was shown in 100m buffers. Aside from the reason for different types or quality of green space, this result may partially be due to the relatively unvaried form of green space in smaller buffers. Although there is a high proportion of green space in NZ, the difference in spatial characteristics between green spaces was small

(Richardson et al., 2010). According to the Attention Restoration Theory (Kaplan & Kaplan, 1989), which explains the restorative effects of green space, a natural environment that provides qualities of 'fascination' (evoke sense of awe and wonder) and 'compatibility' (human goals and environment characteristic align) has the potential to increase an individual's psychological restoration. Emotion is related to the restoration effect (Li & Sullivan, 2016) which is a possible mediator. Therefore, the positive effects of restoration may contribute to the changes in emotion and in turn contribute to mental well-being. Adolescence is a life stage characterised by sensation-seeking (Mueller et al., 2019). It is conceivable that a green space without enough content and variation to support the preference and the purpose of activity could lead to inattention or boredom for adolescents. This may lead to a lack of interest in green space and reduce its positive impact on adolescent mental well-being.

Distance to the nearest green space from the residence was a promising indicator for adult mental health (Gascon et al., 2018; McEachan et al., 2016; Rugel et al., 2019). However, this study showed no association between distance and emotional well-being and depressive symptoms across all models. Distance was used as a proxy for accessibility to green space (Dadvand et al., 2019), but people may be willing to travel longer to more attractive places rather than utilise their nearest green space (Hernández-Morcillo et al., 2013). Adolescents may not have the same independent mobility as adults (O'Brien et al., 2000), and so proximal access to quality and varied types of green space may be important. Combining global positioning systems (GPS) and GIS data to measure adolescents' exposure to, and use of green space alongside characterising the quality, variation and type of green space available and used would be beneficial in future research.

Physical activity

Results of indirect effects illustrated that PA mediator links NDVI to adolescent depressive symptoms and emotional well-being. However, this role was only found in the unadjusted model for the 100m neighbourhood area. Although we had null results of total effects in 100m and 300m buffers in unadjusted models, it is worth noting that a significant relationship between predictors and outcomes is not a prerequisite for examining indirect effects (MacKinnon, 2008). This is partially because additional potential mediators on the pathways weaken the effects of green space exposure on mental well-being, and the indirect effect works in the direction opposite to the direct effect. Results were in line with some adult research indicating a null (Banay et al., 2019; de Vries et al., 2013; Triguero-Mas et al., 2015) or minor (Gascon et al., 2018; McEachan et al., 2016) mediatory pathway through PA, but in contrast to other previous research with adults (Bojorquez & Ojeda-Revah, 2018; Liu, Wang, Grekousis, et al., 2019; Liu, Wang, Xiao, et al., 2019; Qin et al., 2021; Wang, Helbich, et al., 2019; Zhang et al., 2018). One explanation is adolescents may experience barriers to access including poor quality green spaces, or reduced accessibility to green space (e.g., via unsupportive active travel infrastructure) (Smith et al., 2017). A well-designed park could increase the frequency of visits among adolescents (Edwards et al., 2015). Further, people's behaviour in different spatial context may vary due to different forms, designs and infrastructure provided in green space. It is possible that different types of physical activities are undertaken in different park spaces. For example, more physical activity in playgrounds and static activities in areas with seats (Ostermann, 2010).

Besides the reasons above, it is possible that the indirect effect of PA was hidden due to the intertwining of mediators. Dzhambov et al. (2018) found no indirect effect of PA in the parallel mediation model of green space and young adults' mental health. However, in the serial model, PA did have a significant association after adding perceived green space and restorative quality in the pathway. Serial indirect pathways analysis could also be useful to reveal relationships between mediators. Including additional mediators (e.g., air quality, noise pollution) could be worthwhile in future research.

In addition, it is worth noting that the 100m neighbourhood area was the only buffer zone that we detected the mediation of PA. This buffer range is not consistent with previous studies that used ranges of 500m to 1km to explore PA in children and adolescents (Kelso et al., 2021). Considering the relatively larger proportion of younger adolescents ($<$ 16 years old) included in this study (66.4%), parental safety concerns may have restricted adolescent PA locations to those most proximal to home (Akpınar, 2020). It is noteworthy that increased PA was related to adolescent emotional well-being in the current study. This aligns with previous evidence suggesting that green space may encourage PA (Akpinar, 2016; Ward et al., 2016). Therefore, the importance of surrounding green space on promoting PA in neighbourhoods warrants future empirical investigation. Inclusion of more robust PA measurement (e.g., accelerometery) would also be worthwhile.

Social cohesion

In line with Wang et al. (Wang, Meng, et al., 2019), social cohesion did not mediate the pathway between green space and adolescent mental well-being. This differs from findings of studies among adults (de Vries et al., 2013; Liu, Wang, et al., 2020; Wang, Helbich, et al., 2019; Yang et al., 2020). Possible reasons for the variations in effects between adolescent and adult may be due to the different motivators, perceptions, and use of green space as well as the measure used to indicate social cohesion. As Browning and Soller suggested, different from other age groups, adolescents tend to conduct social activity in public spaces that may not be in close proximity to home (Browning & Soller, 2014). In this respect, it is possible that neighbourhood green space may not be a preferred place for adolescents' social activities, and different buffer sizes matter for different activities (e.g., for social versus physical activities). The maximum buffer zone in this study was 1600m, thus, we might not have measured green space that was important for adolescents' social activities. In this respect, we suggest that an expanded buffer zone could be considered for studying the association between green space and adolescent mental well-being, particularly for those associations for which social cohesion are key mediators.

Furthermore, it is plausible that online social networks weaken social interaction in the real world, reducing contacts with green space. As mentioned earlier, social cohesion is a promising mediator because green space provides a public place to increase social contact and enhance social connection. However, online communication has become increasingly important in adolescents' social life (Valkenburg & Peter, 2011), thus declining social contact in person may be occurring (Subrahmanyam & Greenfield, 2008). Notably, our findings indicated that increasing social cohesion is positively related to adolescent emotional well-being. Therefore, more studies are needed to explore how green space can contribute to adolescent mental well-being through supporting social cohesion.

Sleep

Sleep was the only mediator that was detected in 100m, 300m, and 1600m buffers in the relationship between NDVI and adolescent mental well-being. Although the indirect effects disappeared after adding control variables, this study provides a plausible possibility that green space could contribute to sleep, which in turn impacts adolescent mental well-being. Previous studies also showed that sleep was associated with improved mental well-being among adolescents (Hoare et al., 2020; Short et al., 2020). The significance of these findings is put in context when a high proportion of secondary school students report inadequate sleep in NZ (Dorofaeff & Denny, 2006). One possible explanation of the mediation of sleep is that green space can protect from air pollution, extreme temperature, noise pollution and traffic density, which could have a detrimental influence on sleep (Jenerette et al., 2015; Klingberg et al., 2017). Another possible reason is the contribution from other health behaviours, such as PA (Astell-Burt et al., 2013; Shin et al., 2020). Further research is needed to explore if there is an association between green space and adolescent mental well-being through sleep.

Neighbourhood buffer definition

Neighbourhood buffer definition is an important consideration (Mavoa, Bagheri, et al., 2019). In the present study, we only detected the mediatory role in the 100m buffer zone in adolescents regarding PA. This result is different from previous studies that showed that larger distances performed better in identifying relationships between green space and physical activity in which an 800m - 1.6km neighbourhood buffer distance was suggested for older children and adolescents (Smith, Cui, et al., 2021), and an 800m - 1km road network buffer distance for adults (Mavoa, Bagheri, et al., 2019). These variations indicate the importance of understanding the range of determinants for exposure areas, such as how adolescents perceive their neighbourhoods (Robinson & Oreskovic, 2013). Although a previous review recommends distances between 300 and 1600m for adolescent mental well-being related research (Zhang et al., 2020), we suggest employing multiple buffers including the home environment (e.g., 50m neighbourhood buffer distance), particularly for those studying pathways in the relationships between green space and mental well-being among adolescents.

Other social and physical environment factors

It is possible the mental well-being outcomes previously ascribed to green space are actually due to other social and physical environment elements. For example, a Canadian study indicated that population density and walkability influence exposure to green space while considering social interaction as a pathway (Rugel et al., 2019). Flouri et al. (Flouri et al., 2014) found an association of neighbourhood green space and mental health only for children residing in low socio-economic status neighbourhoods. In the current study, higher area-level deprivation (as a control variable) was directly related to lower emotional well-being. Further work exploring inequities in these relationships is needed. These findings reveal the complexity of relationships between green space and mental well-being. Therefore, focused explorations of how social and physical environments modify the effects of green space are needed.

Strengths, limitations and future research

The age group included in this study has almost no previous relevant research (Zhang et al., 2020). It is also the first to explore the pathways between green space and mental well-being in the context of adolescents in NZ. The analysis included a range of potentially important control variables and addressed gaps in previous research.

This study, however, has some limitations. First, this study was not able to consider the subjective experiences of green space, such as usage and perceived usefulness/utility of the green space, which may be critical parts in the relationship between green space and mental well-being in adolescents. Second, this study did not assess the quality of green space. It is possible that green space quality may impact both green space use and the relationship between green space and mental health. A combined metric for public open space quality and quantity (the POSAI, public open space attributable index) has been used previously in Tāmaki Makaurau (Chaudhury et al., 2016). POSAI scores varied across the 146 spaces in eight neighbourhoods, and there was a trend towards lower POSAI scores in lower socio-economic neighbourhoods. The quality assessment component of the POSAI involved manual audits of each public open space, which was not feasible for the current study. Future research would benefit from integrating measures of green space quality that are feasible to assess at scale without compromising the detail achieved through on-the-ground audits (e.g., via citizen science approaches (Barrie et al., 2019; Rydenstam et al., 2020)), and considering potential inequities in green space quality. Third, the lack of information on activity location may lead to assessment bias. Finally, this is a cross-sectional study, and the test of mediation might be overestimated while limiting causal inferences.

Future studies can build on this work. Findings are confined to three mediators due to the data available in the pre-existing dataset; more potential mediators such as restoration, air pollution, and noise should be considered in future studies. While this research focused on neighbourhood green space (aiming to inform urban design approaches), other sites such as home yards and school settings are worth exploring in future research. Findings are limited to adolescents attending school only, future research exploring adolescents not in education is warranted. Future study could combine in-depth assessments of green space characteristics with GPS tracking and precise activity location data to perform a more thorough analysis of the relationship between green space and adolescent mental well-being. Further, it is worth to explore the green space effects in a different social and geographic context. Importantly, future studies should consider carefully the inclusion of individual and neighbourhood factors (e.g., ethnicity, neighbourhood deprivation, rainbow status, gender) that may contribute more to understanding the green space-mental health link. Findings are limited to adolescents who did not self-report having long-term health conditions or disability. Future research focusing on long-term health conditions or disability is ongoing and will be reported separately. These findings are essential to not only comprehend the interaction between social or physical environment and adolescent mental well-being, but may also help to assess and provide new ideas of current efforts that focus on mental well-being of this population.

This study did not consider the influence of blue space or the visibility of green/blue space. Previous research has shown that higher levels of blue space visibility were related to lower psychological distress in adults (Nutsford et al., 2016), and views onto green space increased recovery from stressful experiences among adolescents (Li & Sullivan, 2016). It is possible that blue space is a potential facilitator to adolescent mental well-being, since there is a high degree of proximity to the sea and other bodies of water in Tāmaki Makaurau. Future research would benefit from considering the visibility of green/blue space while exploring adolescent mental well-being.

Conclusions

Overall, although the contribution of green space to facilitate healthy behaviours and better mental well-being was minor and inconsistent in different buffers, the potential positive influences of green space are worth further investigation. Findings provided evidence for the role of PA, social cohesion and sleep in promoting adolescent emotional well-being and reducing depressive symptoms. Thus, it is vital to identify which aspects of green space could support these health behaviours. More research is warranted to fill this research gap, including studies that consider extended buffer zones (to capture potential settings important for social activity), measure actual green space exposure (e.g., using GPS) and activity in green space (e.g., accelerometry), include measures of green space quality (e.g., through audits or citizen science approaches), and consider additional measures of green space (e.g., tree canopy cover).

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Authors' contributions

Conceptualization, YZ and MS; spatial and statistical analyses, YZ, JZ and SM; statistical analyses, YZ; original manuscript preparation, YZ. All authors contributed to interpretation of results, manuscript revisions, and read and approved the final manuscript.

Declaration of Competing Interests

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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Supplementary materials

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