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Neighbourhood blue space, health and wellbeing: The mediating role of different types of physical activity

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ABSTRACT

Background: Evidence suggests that living near blue spaces such as the coast, lakes and rivers may be good for health and wellbeing. Although greater levels of physical activity (PA) may be a potential mechanism, we know little about the types of PA that might account for this.

Objectives: To explore the mediating role of: a) 'watersports' (e.g. sailing/canoeing); b) 'on-land outdoor PA' in natural/mixed settings (e.g. walking/running/cycling); and, c) 'indoor/other PA' (e.g. gym/squash) in the relationships between residential blue space availability and health outcomes.

Methods: Using data from the Health Survey for England (n = 21,097), we constructed a path model to explore whether weekly volumes of each PA type mediate any of the relationships between residential blue space availability (coastal proximity and presence of freshwater) and self-reported general and mental health, controlling for green space density and a range of socio-economic factors at the individual- and area-level.

Results: Supporting predictions, living nearer the coast was associated with better self-reported general and mental health and this was partially mediated by on-land outdoor PA (primarily walking). Watersports were more common among those living within 5kms of the coast, but did not mediate associations between coastal proximity and health. Presence of freshwater in the neighbourhood was associated with better mental health, but this effect was not mediated by PA.

Conclusions: Although nearby blue spaces offer potentially easier access to watersports, relatively few individuals in England engage in them and thus they do not account for positive population health associations. Rather, the benefits to health from coastal living seem, at least in part, due to participation in land-based outdoor activities (especially walking). Further research is needed to explore the mechanisms behind the relationship between freshwater presence and mental health.

1. Introduction

A growing body of evidence suggests that, all else being equal, living near and regularly visiting the coast or other large water bodies (i.e. blue spaces), is associated with better general (Bauman et al., 1999; Burkart et al., 2016; Garrett et al., 2016; Garrett et al., 2019; Humpel et al., 2004; Wheeler et al., 2012) and mental (De Bell et al., 2017; Dempsey et al., 2018; Dzhambov et al., 2018; Gascon et al., 2017; Nutsford et al., 2016; Völker and Kistemann, 2011; de Vries et al., 2016; White et al., 2013a) health. In line with research into the potential health and wellbeing benefits of living near green spaces (e.g. parks and forests), at least three mechanisms might explain these relationships (Dadvand et al., 2016; Grellier et al., 2017; Hartig et al., 2014; James et al., 2016; Markevych et al., 2017; Triguero-Mas et al., 2015). The first potential mechanism is (physical) *harm reduction* where blue spaces, like other natural settings, are associated with lower levels of environmental stressors such as air pollutants and noise (Markevych et al., 2017), and less annoyance due to these stressors (Leung et al., 2017). A second mechanism relates to psychological *restoration*, which implies that blue and other natural environments may share restorative features that can help to alleviate psycho-physiological stress (Ulrich, 1983) and replenish attentional capacities (Kaplan and Kaplan, 1989). A third mechanism proposes that coastal and other aquatic settings may promote personal *capacity building* by encouraging physical activity

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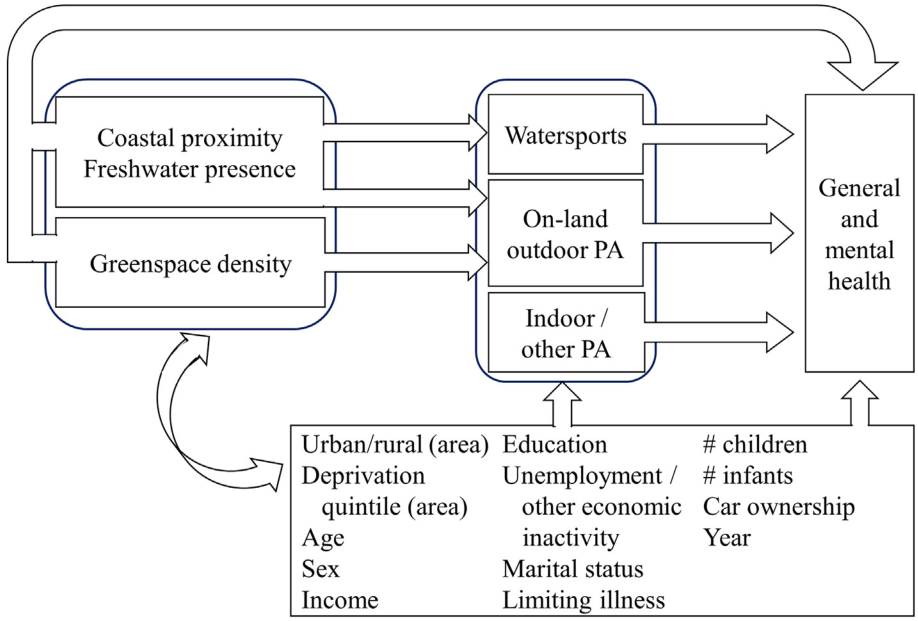

Fig. 1. Conceptual model in the present study.

(PA) and social cohesion (Markevych et al., 2017).

Although compelling, the capacity building mechanism, especially in terms of PA, lacks high quality epidemiological evidence to support it (Gascon et al., 2017; Markevych et al., 2017; van den Bosch and Ode Sang, 2017). A systematic review focusing on blue spaces in particular concluded that current evidence supports the idea that those who have better residential availability of blue space, most often measured by distance to the coast from the home, engage in more PA (Gascon et al., 2017). Regarding freshwater exposure, the evidence was too scant to draw conclusions, although inland waters such as rivers and lakes may afford recreational opportunities such as pathways for walking, similar to coastal settings (Gascon et al., 2017). Yet, we know little about the types of PA that are more commonly undertaken when living near different blue spaces (Gascon et al., 2017). Studies have rarely differentiated between activities occurring outdoors in, on, under, or by water and those conducted in indoor exercise facilities such as gyms in the local area (Gascon et al., 2017; Markevych et al., 2017). Therefore, it is uncertain if the explanatory role of physical activity in blue space-health relationships is limited to certain types of outdoor physical activities, or confounded by indoor physical activities.

However, tentative evidence from England suggests that visits to the coast may explain why people who live closer to the coast are more likely to engage in recommended levels of PA than those who live inland (White et al., 2014). Similarly, an Australian study found that residents in coastal locations reported on average 30 min more walking for exercise per week compared to those in non-coastal locations (Humpel et al., 2004). Furthermore, outdoor recreation patterns in England show that walking, by far the most common type of outdoor recreational activity in England, tends to last longer in coastal settings compared with urban green spaces (Elliott et al., 2015). Therefore, blue spaces may be relevant for public health by not only promoting PA in/on/under the water (i.e. watersports) but also land-based activities by water, such as coastal walking (Elliott et al., 2018), but this has not been extensively explored (White et al., 2016).

Insufficient levels of PA are a major health concern, both globally and within the UK (Hallal et al., 2012). Besides the well-established observation that most forms of PA are beneficial for both general and mental health (Fox, 1999), the setting of PA may provide additional effects. Experimental studies consistently suggest that outdoor PA brings about greater affective benefits than indoor PA (Thompson Coon et al., 2011). Similarly, observational evidence has shown that conducting regular nature-based PA is more strongly connected to some aspects of positive mental health compared to built outdoor or indoor settings (Mitchell, 2013; Pasanen et al., 2014). Further, coastal visits are associated with greater stress reduction (White et al., 2013b), happiness (MacKerron and Mourato, 2013), and connectedness to nature (Wyles et al., 2019) than other natural settings, so it seems plausible that physical activity in such a setting, including both watersports per se, as well as on-land activities such as walking near the water, may be particularly beneficial.

The current research explored these issues using data from a representative sample of the population of England. We examined the relationships between coastal proximity (how close someone lives to the sea) and freshwater presence with self-reported health and well-being, as a function of different types of PA in outdoor and indoor settings: a) in/on/under the water (i.e. *watersports*); b) *on-land outdoor PA* conducted in natural/mixed settings, possibly also by the water (e.g. walking, running and cycling); and c) *indoor/other PA*, conducted in indoor/built settings specifically designed for PA (gyms, swimming pools, sports centres etc.). Considering the importance of walking for public health (Hamer and Chida, 2008; Lee and Buchner, 2008; Robertson et al., 2012), additional analyses separated walking from other on-land outdoor activities. Indoor PA was not assumed to be related to blue or green space due to a lack of theoretical justification for these connections, although it is possible that in greener, coastal, or more rural settings there may be less indoor facilities for PA. Using the theoretical structure shown in Fig. 1, we constructed a path model to explore the mediating role of these different types of outdoor PA blue space – well-being relationships, controlling for potential confounders including green space density. This approach directly addresses one of the research priorities indicated by recent systematic reviews on the topic of blue/green spaces and health (Gascon et al., 2017; Markevych et al., 2017).

2. Material and methods

2.1. Data

The Health Survey for England (HSE) is an annual cross-sectional survey, typically surveying at least 8000 individuals throughout the year (adults and children). The sampling procedure uses a multi-stage stratified probability sampling design for private households in England

Table 1
Summary of the categorisation of different types of leisure time PA.

Intensity	Watersports (Papathanasopoulou et al., 2016)	On-land outdoor PA (Mytton et al., 2012)	Indoor/other PA
Light (2 METs/h)	– Fishing, surfing/wind surfing, sailing, angling	– Walking at an average or a slow pace	– Dancing and “exercises” (if were not out of breath/sweaty) – All ‘other’ light activities
Moderate (4.5 METs/h)	– Fly fishing, snorkelling, water skiing, canoeing, kayaking	– Walking at a brisk or fast pace – Cycling and football/rugby (if were not out of breath/sweaty)	– Dancing and “exercises” (if were out of breath/sweaty) – Swimming, working out/exercise bike/weight training, aerobics or similar, and badminton/tennis (if were not out of breath/sweaty) – All ‘other’ moderate activities
Vigorous (9 METs/h)	– Scuba diving, subaqua diving and rowing	– Running/jogging – Cycling and football/rugby (if were out of breath/sweaty)	– Squash – Swimming[a], working out/exercise bike/weight training, aerobics or similar, and badminton/tennis (if were out of breath/sweaty) – All ‘other’ vigorous activities

[a] Swimming was not distinguished as being indoors in a pool or outdoors in open water; given the likelihood that most swimming is in indoor pools, swimming was classified as indoor PA.

(Bridges et al., 2013). In both 2008 and 2012, selected households were initially approached with an advance letter containing information about the survey, after which trained interviewers made contact to arrange a computer-assisted, face-to-face interview with all adults within the same household (Bridges et al., 2013). More specific details of data collection, sampling, and descriptive statistics are well-documented elsewhere (Bridges et al., 2013). We pooled two waves of the data series, 2008 and 2012, that included additional questions on the amount and types of PA undertaken in the past four weeks. The sample in 2008 consisted of a ‘booster’ sample in addition to the core sample with twice as many respondents in total (Aresu et al., 2009b). In 2012, the sample consisted of 8291 individuals in 5219 households (Bridges et al., 2013), and in 2008, the sample consisted of 15,102 individuals in 9191 households (Aresu et al., 2009b). Due to missing values, mainly in the outcomes (Table 2), the main models analysed here included 21,097 respondents.

2.2. Measures

2.2.1. Area-level environmental indicators

All area-level variables were specified at the Lower-layer Super Output Area (LSOA) level. LSOAs are small geographical areas with an average of approximately 1500 residents in 600 households, and cover, on average, 4 km^2. This unit of analysis is in line with the recommendations to use larger areas than immediate surroundings when assessing the connection between environmental features and PA (Browning and Lee, 2017; Markevych et al., 2017). Since standard HSE datasets only include larger geographical region identifiers, the data owners permitted anonymised linkage of three environmental variables with the approval of the Data Release Panel and the Health and Social Care Information Centre (now NHS Digital). LSOA-level environmental data were provided to the data custodian, where they were linked based on the participant's LSOA of residence and returned without spatial identifiers. In order that residential location could not be reverse-engineered, continuous measures of green and blue space were classified into relatively coarse categorical variables before being supplied to the data custodian, and the returned linked data was stripped of broader regional identifiers.

Coastal proximity was calculated as the Euclidean distance from the population-weighted centroid of the respondent's LSOA to the nearest coastline as derived from open license geographical datasets (Office for National Statistics Geography, 2016). Distances were collapsed into five categories: 0–1 km, > 1–5 km, > 5–20 km, > 20–50 km, and > 50 km consistent with previous research (e.g. Wheeler et al., 2012). To obtain approximately equal sample sizes per category, we combined the first two categories (0–5 km) for current analyses.

Freshwater coverage is relatively low in England compared to other EU countries (overall land coverage 1.3%, Morton et al., 2011), and accordingly, we modelled it as either none or at least some (> 0%), indicating the absence or *presence of freshwater* in the LSOA. This variable was derived from the CEH Land Cover Map 2007 (Morton et al., 2011).

Green space area density (%) within an individual's neighbourhood LSOA was provided to us in 10% bands (< 10%, 10– < 20%, etc.), derived from the Generalised Land Use Database (GLUD) from openly available neighbourhood statistics (Department for Communities and Local Government, 2007). These data include all green spaces (irrespective of public/private accessibility) of minimum size 5 m^2, excluding domestic gardens, and have been used in previous relevant research (Mitchell and Popham, 2007; Wheeler et al., 2012). We rescaled the categories to 1–5 where one scale point increase refers to 20% increase in green space density to ease interpretation.

2.2.2. Leisure-time PA: watersports, on-land outdoor PA, indoor/other PA

Respondents were asked to report all leisure-time PA conducted in the past four weeks. Regarding each activity, they recorded the number of days it was conducted, average duration per bout, and whether the activity had usually made them ‘out of breath and sweaty’; this comprehensive instrument has been developed for accurate assessments of whether respondents meet current PA recommendations (Scholes and Mindell, 2013). Following the official documentation of the HSE (Bridges et al., 2013), each activity was classified in terms of its intensity as light, moderate or vigorous, depending on the type of activity and whether it made respondents short of breath (summarised in Table 1). To calculate proxies for the intensities for each activity, we ascribed Metabolic Equivalents of Task (METs; Ainsworth et al., 2011) rates so that the hours spent on all light activities were multiplied by 2, moderate activities by 4.5, and vigorous activities by 9. This approach reflects the public health recommendations where conducting vigorous activities are considered to be twice as beneficial for health as moderate activities (Scholes and Mindell, 2013).

Using these approaches, we calculated per-person estimates of total MET-h/week, based on previous studies that also used HSE data, for watersports (Papathanasopoulou et al., 2016), on-land outdoor PA (Mytton et al., 2012), and indoor/other physical activities (Table 1). A key sensitivity analysis divided on-land outdoor PA into ‘walking’ and all other on-land outdoor activities (namely running, cycling, football/rugby). In line with the HSE methods documentation, which offers best practice guidance on avoiding undue influence of outliers on any analyses (NatCen Social Research, 2014), the maximum weekly hours for each PA subcategory was truncated to 40. In these cases, the respective MET hours were recalculated by multiplying 40 by the respondents' average PA intensity in that subcategory.

2.2.3. General and mental health

General health was asked with a single item “How is your health in general?" and assessed on a 5-point ordinal scale ranging from 1 'Very bad' to 5 'Very good'. This is a widely used and validated measure for assessing perceived general health (Doiron et al., 2015; Mavaddat et al., 2011) that correlates with numerous objective health outcomes (e.g. mortality; Kyffin et al., 2004) and has been used extensively in previous green/blue space research (e.g. Mitchell and Popham, 2007; Wheeler et al., 2012).

Mental health was assessed with the General Health Questionnaire (GHQ-12; Goldberg et al., 1997). The scale contains 12 items related to issues with mental health in the past few weeks (for example, 'How often have you been feeling unhappy and depressed?'), measured on a 4-point scale ranging from 0 'not at all' to 4 'much more than usual'. GHQ has been widely used in health surveys and in other studies of blue space and mental health (e.g. White et al., 2013a) and thus, to enable comparisons across studies it has been recommended to be used in people-environment studies (Gascon et al., 2015). While we recognize that GHQ-12 scores are a latent construct dependent on the 12 items the questionnaire comprises, we a priori modelled the overall 0–12 score which is in line with established scoring conventions (Goldberg and Williams, 1988) and facilitates comparison with previous research. The scores were inverted so that higher values indicated better mental health. The internal consistency of the scale, measured by Cronbach's α, was high (0.898).

2.2.4. Covariates

We adjusted the analyses for two area-level covariates that may play a role on the quantity and quality of available blue and green space (Markevych et al., 2017; van den Berg et al., 2015): *urban/rural status* (rural including towns, fringes, villages, hamlets, or isolated dwellings) and *deprivation*, measured as the quintile of the Index of Multiple Deprivation (QIMD; Department for Communities and Local Government, 2008, 2011).

In terms of individual- and household-level covariates, we adjusted the analyses for a number of demographic and socio-economic indicators that may influence health or health behaviour based on recommendations from previous literature (van den Berg et al., 2015; Gascon et al., 2015; Gascon et al., 2017; Giles-Corti and Donovan, 2003; Lee and Buchner, 2008). *Age*, *sex*, and *education* (Table 2) could confound blue space – health relationships although supporting evidence is mixed (Bélanger et al., 2011; van den Berg et al., 2015; Gascon et al., 2015; Gascon et al., 2017). *Marital status* can reflect both mental health and PA patterns (e.g. by having a significant other to walk with; Lee and Buchner, 2008). Annual *household income*, being *unemployed* or otherwise *economically inactive* (such as retired or a stay-at-home parent), and *car availability* can influence the green and blue settings one has access to, how much time they have to spend on PA there, and the types of PA they can afford to engage in (van den Berg et al., 2015). The number of *children* or *infants* can have an influence on the quantity and outcomes of visits to green or blue environments (White et al., 2013b). Having a *long-term limiting illness* is directly linked to health and mental health and the ability to visit outdoor spaces (Boyd et al., 2018). Of note, although this variable is often included in such models it may act as a potential mediator in its own right and, hence, confound the associations between environmental indicators, PA, and health. Preliminary analyses, however, found no evidence for confounding effects so it was retained only as a covariate. Finally, as the survey was conducted in two separate waves, we adjusted the analyses for *year* (2008 or 2012) to account for any potential national differences in health behaviour or outcomes.

2.3. Analytical approach

In line with recommendations to use path modelling tools to assess the environment-health mechanisms (Markevych et al., 2017) and recent related work on the topic (Dzhambov et al., 2018), we analysed all our relationships of interest in a single path model using the 'lavaan

Table 2
Sample descriptives. All cases with missing information were excluded from the main analysis (n = 2291, 9.8% of the sample).

Variable	(Category)	n/frequency	Mean/ % of total	SD
General health (1–5)		23,379[b]	3.97	0.95
Mental health (0–12)		21,474[c]	10.6	2.64
Physical activity (MET h/ week)	Watersports	23,388	0.10	1.76
	On-land outdoor PA	23,388	14.58	25.61
	Indoor/other PA	23,388	7.21	17.28
Coastal proximity (km)	> 50[a]	8840	37.8	
	> 20–50	6611	28.27	
	> 5–20	3927	16.79	
	0–5	4010	17.15	
Freshwater presence	None[a]	17,956	76.77	
	Some (> 0%)	5432	23.23	
Green space density (%)	0– < 20	6345	27.13	
	20– < 40	5742	24.55	
	40– < 60	3563	15.23	
	60– < 80	3086	13.20	
	≥ 80	4652	19.89	
Urban/rural status (area)	Urban[a]	18,447	78.87	
	Town & fringe, village, hamlet or isolated dwelling	4941	21.13	
Deprivation (QIMD quintile, area)	1st - Least deprived[a]	5141	21.98	
	2nd	4792	20.49	
	3rd	4676	19.99	
	4th	4517	19.31	
	5th - Most deprived	4262	18.22	
Age (years)	16–24	2538	10.85	
	25–34	3355	14.34	
	35–44	4097	17.52	
	45–54	3908	16.71	
	55–64	3862	16.51	
	65–74	3109	13.29	
	≥ 75	2519	10.77	
Sex	Female[a]	12,949	55.37	
	Male	10,439	44.63	
Equivalised annual household income (in thousands), excluding missing values		18,674	32.42	29.23
Income missing	No[a]	18,674	79.8	
	Yes	4714	20.2	
Education (highest level)	No qualification[a]	5919	25.31	
	NVQ1/CSE, other grade equivalent	1087	4.65	
	NVQ2/GCE, O Level equivalent	4906	20.98	
	NVQ3/GCE, A Level equivalent	3462	14.8	
	Higher education below degree	2577	11.02	
	NVQ4/NVQ5/ Degree or equivalent	4972	21.26	
	NA/no answer/ refused	465	1.99	
Economic activity	In employment/ student[a]	13,097	97.32	
	Unemployed	627	2.68	
	Retired or other economically inactive	9664	41.32	
Long-standing limiting-illness	No[a]	17,567	75.11	
	Yes	5821	24.89	
Marital status	Other[a]	8500	36.34	
	Married, in cohabitation, or civil partnership	14,888	63.66	
Children (aged 2–15)	None	17,480	74.74	
	1	3013	12.88	
	≥ 2	2895	12.37	

(*continued on next page*)

Table 2 (*continued*)

Variable	(Category)	*n*/frequency	Mean/ % of total	*SD*
Infants (aged 0–2)	None	21,477	91.83	
	≥1	1911	8.17	
Car availability	No[a]	4521	19.33	
	Yes	18,851	80.6	
	NA/missing	16	0.07	
Survey year	2008[a]	15,098	64.55	
	2012	8290	35.45	

[a] Category used as the reference in the path model; variables without referents modelled as 'continuous'.
[b] Missing $n = 9$ (0.04%).
[c] Missing $n = 1914$ (8.18%).

survey' package (Oberski, 2014) in R version 3.3.3 (R Core Team, 2017). 'Lavaan survey' is an extension of the 'lavaan' package (Rosseel, 2012), designed for latent variable modelling, that calculates cluster-robust standard errors (SE) for a clustered sample (i.e. individuals within the same household) without specification of a multilevel model as such (McNeish et al., 2017). The main models are estimated with a maximum likelihood estimator with robust standard errors and a Satorra-Bentler scaled test statistic (MLM), robust to non-normality (Rosseel, 2012); an important consideration as outcomes and mediators were skewed (Supplementary Figs. A.1 and A.2). Because we used an estimator robust to non-normality, we did not transform any variables; this also provides coefficients which are more readily understandable. Although our health outcomes were measured in an ordinal scale (either 1–5 or 0–12), the use of linear estimation methods is justified as they have been found to be robust in large epidemiological samples (Lumley et al., 2002; Norman, 2010).

All 'not applicable' or 'refused' responses were recoded as missing (Table 2), with the exception of household income that showed a high number of missing values ($n = 4714$). In this case, to avoid systematic biases and to retain more data, all cases with income missing were recoded into 0, and we added a new binary variable in the models to indicate whether income was missing or not (Pedersen et al., 2017). As for coastal proximity, area-level deprivation and education, all variables that were ordered with unequally spaced categories, we tested whether including them in the model as 'continuous' or categorical variables (with the first category being the reference, see Table 2) would fit the data better (in terms of Akaike's and the Bayesian information criteria). In all cases, the categorical operationalisations fitted the data better and were subsequently adopted.

All environmental indicators, PA mediators, and health outcomes were included in the same analysis to account for their likely covariation. The error variances between outcomes as well as those between the PA variables were free to correlate. In the results, we were particularly interested in whether the indirect pathways from environmental indicators to the outcomes via outdoor PA statistically differed from 0 (that is, the estimate's $p < .05$ and 95% CI does not overlap with 0) using the delta method. We also conducted Wald's tests to compare the size of the indirect effects on the same outcomes.

2.4. Sensitivity analyses

To investigate whether walking, as the most common outdoor physical activity (Bélanger et al., 2011), might be the key on-land outdoor activity driving any mediation effects, additional analyses were run where on-land activities were separated into a) 'walking only' and b) 'all other' activities combined (namely, running, cycling and football/rugby), resulting in a model with four potential mediating pathways through PA (Sensitivity model 1).

Further sensitivity analyses were also run to make sure our models and main results were not merely due to specific model specifications. First, to ensure our approach to handling missing data for household income did not bias our main results, we re-estimated the models in two ways: excluding respondents whose income was unknown (resulting in $n = 17{,}195$; Sensitivity model 2a), and excluding income as a covariate altogether (Sensitivity model 2b). Second, as our health outcomes were not continuous (and skewed), we wanted to ensure our operationalisations did not affect the results and thus specified them as 'ordinal', and accordingly used a weighted least-square estimator (Sensitivity model 3). With this approach, however, the cluster-robust standard errors were not available (Rosseel, 2012). Third, we also examined all PA categories in terms of weekly hours conducted to see if it was the time spent being physically active, irrespective of intensity, that was associated with general and mental health (Sensitivity model 4). Fourth, to evaluate whether the environmental indicators could be related to the 'indoor/other PA' category due to e.g. less indoor facilities for PA in greener and possibly more rural settings, we specified a model with all paths from the environmental indicators to all PA variables (Sensitivity model 5). This type of model is saturated with 0 degrees of freedom, which means that the information on model fit is limited. Sixth, to evaluate the benefits of fitting a more comprehensive model, we specified and assessed single mediation models (with one explanatory variable, mediator and outcome at a time) corresponding to all indirect effects in the main model, both unadjusted and adjusted for the same set of covariates as the main model. Seventh, to assess any potential multicollinearity between blue and green space measures, we ran a model without coastal proximity and freshwater presence to examine if they confounded the effects of green space.

3. Results

3.1. Sample descriptives

On average, respondents rated their general and mental health in the past four weeks as good (Table 2; Supplementary Fig. A.1). In terms of PA patterns, in line with previous studies, the rates for watersports were relatively low in the sample (Papathanasopoulou et al., 2016; Elliott et al., 2018) whereas the majority of weekly MET hours were spent on on-land outdoor PA (Table 2; Supplementary Fig. A.2), mostly walking (mean 11.2 MET h/week, analysed in a separate model; see Section 3.4). The average PA rates, presented in Table 2, are approximately equivalent to 1 min (watersports), 151 min (on-land outdoor PA), and 75 min (indoor/other PA) of weekly cycling at a leisurely speed of 9.4 miles/h (equivalent to 5.8 METs/h; Ainsworth et al., 2011).

Regarding blue space indicators, the respondents most commonly lived > 50 km from the coast (38%), while less than a fifth lived within 5 km (17%, Table 2). Nearly a quarter had at least some freshwater in their area.

The intra-class correlations, reflecting the variance shared between the respondents in the same households, were substantial for all mediators and outcomes: 0.381 for general health, 0.221 for mental health, 0.118 for watersports, 0.230 for on-land outdoor PA, and 0.175 for indoor/other PA. The correlation coefficients between the outcomes and mediators are provided as a Supplementary material (Table A.1).

3.2. Model fit and variances explained

The model showed excellent fit with the data: χ^2 (robust) = 0.059, df = 6, p = 1.000; CFI = 1.00; TLI = 1.06; RMSEA < 0.001; SRMR = 0.001. The largest normalised residuals were within acceptable limits (Kline, 2016); 1.23 and 0.89, and all others were < $|0.34|$. Modification indices showed no apparent missing paths. The variances explained in the outcomes were 36.2% for general health and 12.2% for mental health. The model explained a smaller, yet still substantial share of variation in outdoor PA on land (5.2%) and other PA (6.8%), whereas outdoor PA on water was poorly explained (0.3%; Ferguson,

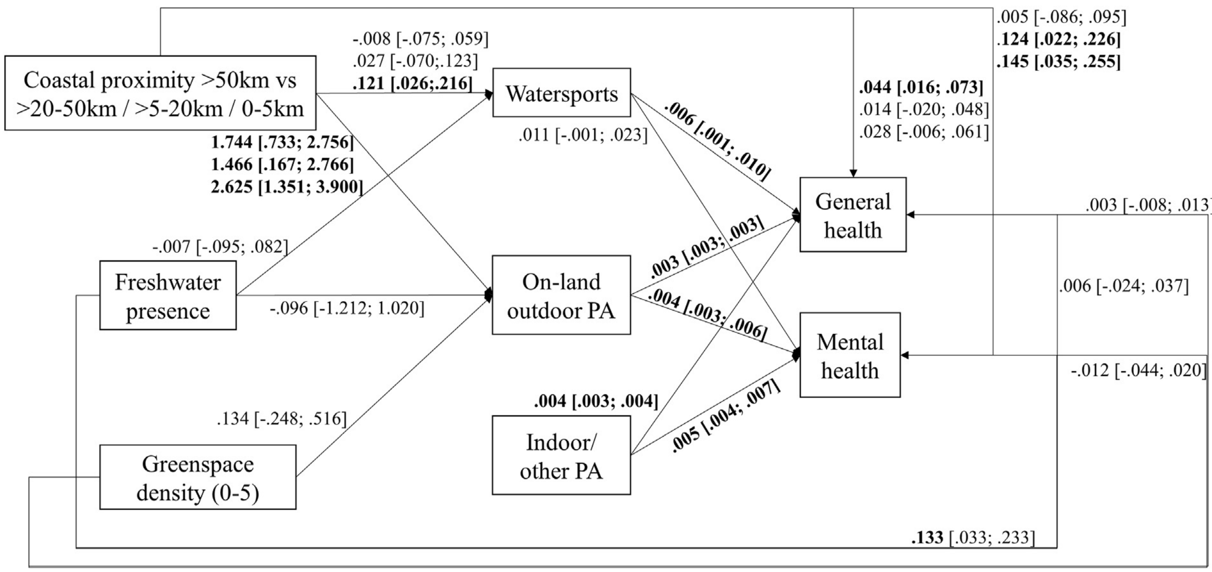

Fig. 2. Unstandardised estimates and their 95% CIs in the path model (n = 21,097), adjusted for all covariates (provided in Supplementary Table B.1). All PA variables are measured in MET h/week. Error covariances between the mediators and the outcomes are not shown for readability but they are provided in Supplementary Table B.1. Bold typeface indicates statistical significance.

2009). We suspect this is due to overall low levels of watersports in general (Table 2).

3.3. Model estimates

Compared to people who lived > 50 km from the coast, those who lived in all distance bands closer to the coast reported more on-land outdoor PA, with the effect strongest for those living < 5 km (Fig. 2, Table 3). On-land outdoor PA in turn was associated with significantly better general and mental health. These connections were strong enough to establish significant indirect connections from coastal proximity to general and mental health via on-land outdoor PA (Table 3). Wald's tests indicated that these indirect effects were approximately equal. Those who lived < 5 km from the coast reported more watersports than those living > 50 km from the coast (b = 0.121, s.e. = 0.048) but the indirect effects on general and mental health were small and not statistically significant (Table 3). Mental health was 0.124 and 0.145 units greater (on the 0–12 scale) for those living 5 km–20 km and < 5 km from the coast, respectively (compared with > 50 km), whereas general health was 0.044 units greater (on the 1–5 scale) for those living 20–50 km from the coast, compared to > 50 km (Fig. 2, Table 3). Overall, the strongest total effect between coastal proximity and outcomes was that from coastal proximity < 5 km versus > 50 km on mental health (Table 3).

Freshwater presence was directly connected to better mental health (b = 0.133, s.e. = 0.051) but there was no significant association with on-land outdoor PA or watersports (Fig. 2, Table 3). Contrary to expectations, green space density was associated with neither outdoor PA, general health nor mental health (Fig. 2, Table 3).

All covariates, except rural/urban status, showed significant associations with at least one of the outcomes or the mediators (Supplementary Table B.1). The associations for the socio-economic covariates were mostly in the expected directions (for example, more educated individuals were generally healthier and conducted more PA). Regarding the correlates of PA, car ownership was associated with less on-land outdoor PA but more for indoor/other PA.

3.4. Sensitivity analyses

Results for our first sensitivity analysis, which disaggregated all on-land outdoor PA into walking vs. other (i.e. running, cycling, football/rugby) can be seen in Appendix C. This model also showed good fit, although the variance explained for walking itself was relatively low (1.9%) in comparison to all other on-land outdoor activities (7.6%; Supplementary Tables C.1 & C.2). Most importantly, the associations between coastal proximity and walking were significant and similar -although weaker- to those in the main model regarding all outdoor on-land PA, whereas the associations between coastal proximity and the

Table 3
Total, direct, and indirect effects (estimates and 95% CIs) from blue/green space indicators to general and mental health via watersports and on-land outdoor PA. In bold: $p < .05$. If the estimate is $|< 0.001|$, no CI shown for clarity.

Env. indicator	Health outcome	Total effect	Direct effect	Indirect effects via	
				Watersports	On-land outdoor PA
Coastal proximity (20–50 km vs. > 50 km)	General	**0.049 [0.021;0.078]**	**0.044 [0.016;0.073]**	< |0.001|	**0.005 [0.002;0.008]**
	Mental	0.012 [−0.078;0.102]	0.005 [−0.086;0.095]	< |0.001|	**0.008 [0.003;0.012]**
Coastal proximity (5–20 km vs. > 50 km)	General	0.019 [−0.015;0.053]	0.014 [−0.020;0.048]	< |0.001|	**0.004 [0.001;0.008]**
	Mental	**0.130 [0.028;0.232]**	**0.124 [0.022;0.226]**	< |0.001|	**0.006 [< |0.001|;0.012]**
Coastal proximity (0–5 km vs. > 50 km)	General	**0.036 [0.003;0.070]**	0.028 [−0.006;0.061]	0.001 [< |0.001|;0.001]	**0.008 [0.004;0.012]**
	Mental	**0.157 [0.048;0.267]**	**0.145 [0.035;0.255]**	0.001 [< |0.001|;0.003]	**0.011 [0.005;0.018]**
Freshwater presence	General	0.006 [−0.024;0.037]	0.006 [−0.024;0.037]	< |0.001|	< |0.001|
	Mental	**0.132 [0.032;0.232]**	**0.133 [0.033;0.233]**	< |0.001|	< |0.001|
Green space density	General	0.003 [−0.007;0.013]	0.003 [−0.008;0.013]	na	< |0.001|
	Mental	−0.011 [−0.043;0.021]	−0.012 [−0.044;0.020]	na	0.001 [−0.001;0.002]

remaining on-land outdoor physical activities were much weaker and not significant (Supplementary Table C.1, Fig. C.1). Walking also showed a positive indirect effect from coastal proximity to general and mental health (Supplementary Table C.2). These results suggest that it was indeed walking, rather than other forms of on-land outdoor PA which may be mostly responsible for the mediation pattern we see between coastal proximity and general and mental health in the main model.

In addition, Sensitivity model 1 indicated that some of the covariates were differently associated with walking and other on-land outdoor PA. For example, gender, age, and income were either weakly or not associated with walking but significantly explained other on-land outdoor PA (Supplementary Table C.1). Regarding education, the reverse was true so that the more educated walked more but did not conduct more of other types of on-land outdoor PA, compared with those with less formal education.

Main results regarding the associations between blue spaces, outdoor PA, and the health outcomes were replicated in most sensitivity analyses, adding confidence to our findings. In Sensitivity models 2a (Appendix Table D.1) and 3, the estimates between coastal proximity and watersports were, however, smaller than in the main model ($b = 0.090$–0.010, s.e. = 0.046–0.060) and not statistically significant; in addition, both models showed a positive but weak connection between green space density and general health ($b = 0.013$, s.e. = 0.005–0.006) but no connection between 5 and 20 km distance to the coast and mental health. In Sensitivity model 3, coastal proximity < 5 km was also weakly but significantly connected to general health ($b = 0.052$, s.e. = 0.022). In Sensitivity model 4, measuring PA in weekly hours (Appendix Table E.1), the relationship between coastal proximity 5–20 km (versus > 50 km) and on-land outdoor PA was positive but not statistically significant. Sensitivity model 5 (Appendix Table F.1), with all possible paths assessed, did not substantially differ from our main model.

The sixth set of sensitivity analyses assessed each indirect relationship separately. The models that were unadjusted for the covariates replicated the results regarding the associations between the environmental indicators and outdoor PA, whereas there were some inconsistencies in the direct associations between environmental indicators and the outcomes. Unexpectedly, many of the adjusted single mediation models had issues with convergence. These seemed to have been caused by one/some of the covariates but we could not identify a single one that would have solved these issues in all models. Hence, in the case of this study, assessing associated mediation mechanisms between environmental exposures and health outcomes in parallel (that is, in a single model) was not only the recommended (Markevych et al., 2017) but also a necessary approach to be able to adjust the model for a large number of a priori chosen potential confounders.

Finally, the model without blue space indicators (Sensitivity model 7), showed a small effect between green space and general health (b = 0.009, s.e. = 0.004, p = .026) but no associations with mental health or any of the mediators, implying that the lack of significant associations between green space and PA/outcomes was not merely due to multicollinearity.

4. Discussion

4.1. Main findings

Supporting previous work globally (Gascon et al., 2017), the current study found that coastal respondents in England reported: a) better general health (e.g. Wheeler et al., 2012); b) better mental health (e.g. White et al., 2013a); and c) more recreational PA (e.g. White et al., 2014), than those living inland. Extending previous findings, we were able to: a) disaggregate recreational PA into different types (e.g. watersports, outdoor on-land, and indoor); and b) show that it was the amount of on-land outdoor recreational activity (especially walking), as opposed to watersports, which mediated the relationships between coastal proximity and both general and mental health. Put simply, adults in England who reside in coastal areas tend to be happier and healthier than similar individuals inland, in part because they engage in more outdoor physical activity such as walking.

The relationships were meaningful in terms of scale. For instance, the difference in on-land outdoor PA between living < 5 km from the coast compared with > 50 km away was equivalent, for example, to cycling 14–40 min more per week at 9.4 mph (equivalent of 5.8 METs/h; Ainsworth et al., 2011). These relationships held in a series of sensitivity analyses. Our findings suggest that a part of the positive association between coastal proximity and mental health, established in previous research (e.g. Gascon et al., 2017) can be explained by PA conducted outdoors on land, and thus highlights the importance of capacity building (Markevych et al., 2017) as one of the mechanisms behind this association. Yet, there remained a substantial share of the variance in our outcomes that was not related to PA, which could be due to the other established mechanisms such as social cohesion and stress reduction (Gascon et al., 2015). Furthermore, while it may be plausible to assume that those living the closest to the coast may use coastal settings for their PA routines (e.g. White et al., 2014), we can only speculate if this is true for residents of areas 5–50 km from the coast who also showed increased amounts of outdoor PA compared with those living more inland. It could be that in these areas not in immediate vicinity of the coast, other amenities account for increased on-land PA. Alternatively, residents in these areas may use the coast for PA less frequently but compensate by staying longer and consuming more energy per visit (Elliott et al., 2015). Further research is needed to investigate these possibilities.

Walking, apart from other on-land outdoor PA, partially mediated the relationship between residential coastal proximity and both general and mental health. Respondents living within 5 km of the coast on average undertook 20–56 min more of weekly, moderate-intensity walking (equivalent of 3.5 METs/h; Ainsworth et al., 2011) compared to those further inland. In line with previous work, this could indicate that walking is a popular activity to do at coastal environments (Elliott et al., 2018) that is sufficiently health-enhancing (Elliott et al., 2015), but we cannot definitively state that the actual coastline supported walking, as it may be that coastal towns and cities simply have better infrastructure for walking. Nonetheless, the development of England's fully publicly accessible coastline (Natural England, 2013) could indicate that areas in very close proximity of the sea are used for health-enhancing physical activity. This finding also has important public health implications. Previous research has demonstrated that walking, separately from all other forms of PA, can protect against physical health challenges like cardiovascular disease (Hamer and Chida, 2008) and mental health difficulties like depression (Robertson et al., 2012), and thus coastal environments could reduce the national burden of such diseases through supporting PA.

We also found evidence of a positive connection between residential freshwater coverage and mental health. This association was, in effect size, comparable to coastal proximity (< 5 km vs. > 50 km). Contrary to coastal proximity, however, the positive connection between freshwater presence and mental health was not mediated by any type of outdoor PA. It remains a topic for future studies to examine other mechanisms that link freshwater presence and mental health. Tentative evidence suggests that this connection could be better explained by perceived psychological benefits and social interaction (De Bell et al., 2017). Alternatively, the recreational use of freshwater settings in England may be limited by their small size and issues with quality and amenities such as cleared pathways. For example, some estuarine areas are counted in the freshwater measures but they might not be suitable for recreational use due, for instance, to varying levels of water coverage.

Green space was not significantly associated with general or mental health, or any PA type. This result contrasts with many previous studies. One possibility might be that residential blue space is more strongly connected to mental health than green space (Nutsford et al., 2016; de Vries et al., 2016), however far more research is needed before such a conclusion can be made, not least greater clarity about the types of, and access to, different sorts of green and blue spaces in different residential areas. Another plausible explanation for these null findings could be that we had no available measure of perceived green space or its quality. Recent evidence suggests that greenery visible on the street level may be more relevant for mental health than greenery measured from the aerial perspective (Helbich et al., 2019). Relatedly, another possibility for the lack of association between area-level greenspace and health outcomes is the greater measurement error in how green space is assessed. While we can be reasonably confident that Euclidean distances to coasts are measured accurately, percentages of green space are dependent on a number of other assumptions about what constitutes "green space" and how and when land use maps are produced (Helbich, 2019). For example, the presence of street trees has been show to correlate with indicators of physical (de Vries et al., 2013) and mental (Taylor et al., 2015) health previously, but could not be accounted for in the present study. Thus, here we potentially underestimated exposure to green space. Furthermore, quality issues, such as facilities, connectivity, cleared pathways, and restorative perceptions may also be more relevant than density in terms of how green spaces are used (Dzhambov et al., 2018; Francis et al., 2012). The relationship between green space and PA may also vary between different green space indicators and buffers (Klompmaker et al., 2018). Options for capturing better the environments visited in everyday life for PA include dynamic exposure assessments (Helbich, 2018) and assessing larger areas or buffers around one's residence (Browning and Lee, 2017). However, in the case of our study, using a larger surrounding area may have resulted in the same conclusions. This was indicated by Mytton et al. (2012) who used earlier waves of the HSE with green space measured on the geographically larger middle super output area (MSOA) scale (as opposed to LSOAs used here), and found no association between green space and outdoor PA either. Although systematic reviews have often concluded that there seems to be a positive but small connection between green space and outdoor PA, there are a large number of studies that also report no such relationship (van den Bosch and Ode Sang, 2017; Klompmaker et al., 2018). Finally, recent research using English population data indicates that dog ownership may be an important moderator of the association between neighbourhood green space density and PA (White et al., 2018); since the HSE does not include information on dog ownership in the same years as physical activity we could not investigate this here, but it may have confounded our findings.

4.2. Strengths, limitations and further studies

Our paper makes several contributions to the field. First, we address the role of physical activity, one of the major pathways that links residential blue and green spaces to health and well-being, in greater detail than many previous studies in this topic (Markevych et al., 2017). By separating physical activity into watersports, outdoors on-land, or in indoor/other, we can better understand how residential neighbourhood environments and their use are associated with general and mental health (Markevych et al., 2017). Second, we have a large epidemiological dataset with standard, reliable measures of general and mental health. The survey data permitted adjustment of analyses for a large number of potential confounders addressed in past research without compromising on statistical power, and our results on these variables are comparable with other studies (van den Berg et al., 2015; Gascon et al., 2017; Markevych et al., 2017). Third, by using path modelling as our analytical approach, we assessed the interrelationships between residential blue and green space, PA in different types of settings, and general and mental health in a single model (as recommended by Markevych et al., 2017). This way potential confounding between the mediators, outcomes, and explanatory variables is better accounted for than in the case of more simplistic models that analyse these variables separately. However, we did not assess whether some of the covariates, such as socio-economic factors (Wheeler et al., 2012), moderate the associations between coastal proximity and PA or the outcomes; these were outside the scope of this study but worthy of investigation in the future. Fourth, although outdoor PA, especially walking, seems tentatively more frequent near blue spaces than further from them (e.g. Humpel et al., 2004), to our knowledge no previous epidemiological studies have assessed whether this relationship is strong enough to associate with better perceived general or mental health (Gascon et al., 2017).

However, this study is was not without limitations, and many of these are typical for studies based on cross-sectional survey data. This study cannot imply causality, of which evidence is generally limited (Gascon et al., 2015). Based on our analysis we can say that those who live closer to the coast conduct more outdoor PA (especially walking) and feel healthier than those living > 50 km away from the coast. However, we cannot say whether more active and healthier people tend to move closer to the coast or if it is coastal proximity that encourages people to be more physically active and, consequently, healthier. Moreover, we relied on self-reported PA in the current analyses when there is evidence that these may be exaggerated (Hagstromer et al., 2010). Although a sub-sample of the 2008 HSE participants did wear accelerometers for a period during the study, we were unable to use this data here because it was not linked to information on the activities or geospatial factors. Even if we had have been able to use it here, neither self-report nor objectively-measured PA is perfect, of course: while self-reports tend to be exaggerated, the overestimations are relatively similar across different demographic groups and activities, whereas accelerometry is unable to capture some common activities such as cycling and, of potentially crucial importance for the current work, swimming and other watersports (Aresu et al., 2009a).

The current work was also limited by relatively coarse environmental data being appended by the data provider which was necessary to ensure respondent anonymity. For this reason we were not able to assess any regional or seasonal patterns (Scholes and Mindell, 2013), or to measure green space or freshwater elements in larger areas surrounding the respondents' homes (e.g. by identifying neighbouring areas or by calculating these indicators within a set distance), which may be more relevant in terms of PA behaviour (Giles-Corti et al., 2005). Being restricted to analysing all environmental information at the LSOA level prevented us from assessing the modifiable area unit problem, that is, if using other administrative boundaries or buffers would have yielded different results (although we do find comparable results to those of Mytton et al. (2012) on greenspace and PA using larger spatial units as described above). Similarly, we were unable to obtain the exact values for our environmental indicators (such as exact distance to the coast or green space density) but could only use broad categories that prevented more refined analysis.

Finally, in terms of limitations, although we had precise information on the type of PA conducted, we could not link those activities specifically to a certain setting or a type of setting, a research priority stated by Markevych et al. (2017). Thus, our PA categories were based solely on activities and were quite broad. Some activities classified as 'indoor/other PA' could have been conducted outdoors. In the sensitivity analysis (Appendix Table F.1) where we assessed the relationship from the environmental indicators to 'indoor/other PA', none of the associations were significant, potentially justifying our assumption that the major forms of outdoor PA were captured by the 'on-land outdoor PA' measure (Mytton et al., 2012). Regarding watersports, the biggest drawback was that we could not reliably include swimming in the measure since there was no information on whether swimming was conducted indoors or outdoors. This may partly explain why watersports, as a group of activities, were relatively uncommon (although the result is consistent with other surveys; Elliott et al., 2018); its variance explained was low, and it showed few associations with covariates and outcomes. Future studies could reduce this problem by endeavouring to ask separately about indoor and outdoor swimming, and preferably differentiate between built/artificial swimming pools and beaches.

Longitudinal studies are needed to examine the effects of moving closer to, or further from the coast, on PA levels (see White et al., 2013a for a similar approach exploring general and mental health over time). Also country-specific and contextual patterns would be useful to examine to see whether our results are replicated or contrasted in other countries and regions. Differences in cultural patterns of outdoor recreation and environmental qualities and facilities may impact how coastal, inland, and green settings are used and how their usage in turn affects general and mental health. In England, coastal settings are accessible and managed so that they are suitable for outdoor recreation and walking (Natural England, 2013). Whether similar infrastructure in other countries or regions could promote PA near coastal surroundings is worthy of investigation. Given the apparent importance of walking in coastal areas, proximity to accessible freshwater 'edges' (which may similarly represent PA opportunities such as riverside paths) may be a more appropriate inland blue space measure for future research than the area coverage that was available for this study. Finally, many epidemiological studies such as the present one do not allow for refined analysis on different aspects of environmental quality. More research efforts using mapping tools that locate PA to specific settings are needed to complement the population-level studies with more detailed analyses on the types of settings that promote better general and mental health.

4.3. Conclusion

This is the first UK study to provide clear evidence that benefits to health and wellbeing associated with living near the coast are partially mediated through outdoor physical activity. Sensitivity analyses found that walking, by far the most common type of PA and less susceptible to socio-economic or demographic differences, is more common nearer the coast, and partly accounts for why living close to the coast is related to better general and mental health. However, the different types of outdoor PA explain only a part of the coastal proximity-health relationship, indicating that other mechanisms also play a role. Having freshwater blue spaces, such as rivers and lakes near one's home was also associated with better mental health but this association was not mediated by PA, suggesting other factors could be more important. In sum, extensive analysis of two waves of the Health Survey for England, suggested that, all else equal, living near water was associated with better self-reported mental and physical health and that greater amounts of physical activity appears to account for at least part of these relationships, especially among those living near the coast.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

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