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Longitudinal Effects on Mental Health of Moving to Greener and Less Green Urban Areas

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Supporting Information

ABSTRACT: Despite growing evidence of public health benefits from urban green space there has been little longitudinal analysis. This study used panel data to explore three different hypotheses about how moving to greener or less green areas may affect mental health over time. The samples were participants in the British Household Panel Survey with mental health data (General Health Questionnaire scores) for five consecutive years, and who relocated to a different residential area between the second and third years (n = 1064; observations = 5320). Fixed-effects analyses controlled for time-invariant individual level heterogeneity and other area and individual level effects. Compared to premove mental health scores, individuals who moved to greener areas (n = 594) had significantly better mental health in all three postmove years (P = .015; P = .016; P = .008), supporting a "shifting baseline" hypothesis. Individuals who moved to less green areas (n = 470) showed significantly worse mental health in the year preceding the move (P = .031) but returned to baseline in the postmove years. Moving to greener urban areas was associated with sustained mental health improvements, suggesting that environmental policies to increase urban green space may have sustainable public health benefits.

INTRODUCTION

Unipolar depressive disorders are now the leading cause of disability in middle to high income countries,[1] making mental health and wellbeing a critical modern public health issue. This trend may be related to increased urbanisation,[2] with 77.7% of people in the world's more developed regions now residing in urban areas, and to reduced access to "natural" spaces which aid stress reduction.[3,4] Support for this possibility comes from epidemiological studies which find that individuals living in the greenest urban areas tend to have better mental health than those in the least green areas.[5,6] Similar patterns are found for a range of physical health outcomes,[7] including mortality.[8] Experimental findings and field observations on the effects of green space exposure on psychological health are also consistent with this epidemiological evidence.[9,10]

However, to date most epidemiological research has used cross-sectional data which limits causal inferences.[10,11] Are people happier and healthier due to the proximity of green space to their homes, or do healthier people move to greener areas? Such selective migration might result from people who are already more physically active moving to areas that provide exercise opportunities,[13] or the higher incomes of people with good mental health[14] enabling them to pay higher housing costs in greener areas.[15]

Recent analysis of repeated measures data from the British Household Panel Survey (BHPS) has begun to address these possibilities. Urban green space was shown to be positively associated with better mental health measured by the General Health Questionnaire (GHQ), using fixed effects (FE) regression, which controls for time-invariant factors such as personality.[16] Although this finding is encouraging for the hypothesis that living in a greener areas aids mental health, the analysis was unable to comment on the progress of mental health over time following changes in residential area green space. The current paper uses the same longitudinal data set to address this gap.

Take, for example, someone moving from an urban area with little green space to one with a lot of green space. Although their mental health may be better, on average, across the years following the move, this average improvement may reflect a number of possible temporal processes. First, there may be initial improvement in mental health, followed by a decrease in benefits as individuals adapt to their new greener surroundings and the novelty wears off—an *adaptation hypothesis*. Under this possibility the higher overall average is due only to an increase in the first couple of years. Alternatively, there may be little initial benefit from moving because, for instance, it takes time

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to get to know where local parks are and to begin to use them. Only as these new opportunities are taken up does mental health improve gradually—a *sensitization hypothesis*. In this case the higher overall average is only due to later years. Finally, mental health may improve directly following a move to a greener area and remain at a similar heightened level thereafter—an immediately *shifting baseline hypothesis*. Figure 1 presents graphical representations of these three theoretical possibilities. Of note, the 3 year mean level of well-being postmove is equivalent in each scenario despite the different underlying processes.

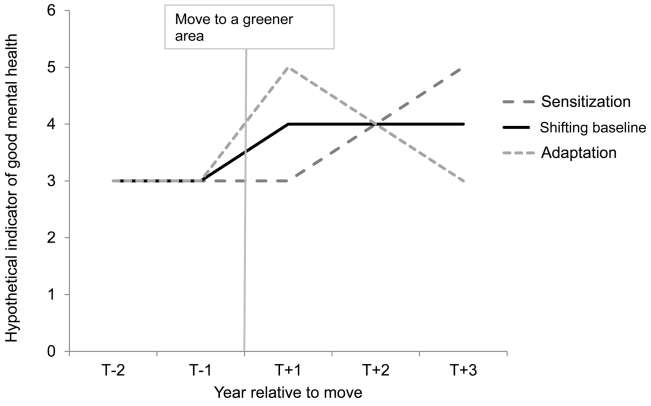

Figure 1. Three hypothetical temporal patterns in mental health improvement following moves to greener urban areas. Note: T−1 and T+1 are annual data collection time points immediately prior to and succeeding the time of the move to a greener area. T−2 is the annual data collection time point preceding T−1, and T+2 and T+3 are the annual data collection time points succeeding T+1.

Investigating these possibilities is relevant because mental wellbeing trajectories matching all three processes have been identified following other life events using longitudinal data sets.[17,18] For instance, *adaptation*, (i.e., full or partial return to baseline quality of mental health), has been found following both positive life events such as getting married[19] and achieving promotion,[20] and negative events such as needing regular medical treatment,[21] or becoming divorced.[22] The frequency with which this phenomenon is observed has led some researchers to suggest that people have a "set point" level of mental well-being which they tend to return to fairly quickly after either a positive or negative perturbation (see ref 17 for discussion). *Sensitization*, (i.e., gradual change in mental health over time in reaction to a stimulus), has also been found following positive events, including windfalls from small lottery wins,[23] and negative circumstances such as environmental noise.[24] Finally, a *shifting baseline*, (i.e., a relatively swift but stable alteration to a new state of mental health), has also been found following both negatives events such as unemployment,[25] and positive interventions such as cognitive-behavioral therapy for people with moderate-to-mild depression.[26]

Knowing which of these three processes is at work is important for at least two reasons. First, around 10% of households in most OECD countries, and 20% in the U.S. and Nordic countries have relocated within the last two years, and thus issues of home relocation are pertinent to millions of people annually.[27] Second, the theoretical patterns of how mental health may be affected by moves to greener/less green urban areas have different implications for planning policies interested in improving population well-being through environmental interventions. Support for the adaptation hypothesis, for instance, would suggest that benefits from introducing new urban parks may be short-lived, whereas support for the alternative hypotheses would suggest more sustainable benefits. To investigate which of these theoretical temporal patterns in mental health is associated with moving to greener/less green urban areas, we used GHQ data from five consecutive annual survey waves of the BHPS, including two years before, and three years after, residential area relocation.

MATERIALS AND METHODS

Samples. Adult samples were drawn from the BHPS, a nationally representative longitudinal survey of over 5000 UK households that ran annually from 1991 to 2008.[28] The analyses investigated GHQ scores of two subsets of respondents: those who moved to greener urban areas, and those who moved to less green urban areas. Estimation samples were limited to English residents, and BHPS respondents from Wales, Scotland, and Northern Ireland were excluded, as data on local area green space was from a database which covered only English residential areas. Relocations were also restricted to those within urban areas to avoid confounding green space with urbanity.[29] Analyses used balanced panels with full data for six consecutive data waves, where the first three waves were in one location, and the last three were in the other. The six waves may come from any six-year period in the panel, ranging from 1991−1996 to 2003−2008. Where a panel member had data from more than one series of six waves, only the earliest was included in our samples. Observations from only five of these six years were analyzed in our models (see below).

The analyses used balanced panels, as this gave continuous data for testing hypotheses about stability over time and a high degree of certainty that all relocation events within these periods were accounted for. Although it is conceivable that relocations both away from, and immediately back to, an area might have occurred between two data collection wave points, bias from such rare events is likely to be negligible. We restricted the time range to six years because further extensions resulted in substantial reduction in sample size due to item nonresponse on predictors and panel attrition. These inclusion criteria resulted in samples of 594 movers from areas of less to more urban green space (2970 observations), and 470 movers from more to less green space (2350 observations).

We used 'T' to denote the time of the relocation, and "T−1" and "T+1" to denote the annual data collection waves immediately before and after relocation. The second wave in the series of six ("T−2") was defined as the baseline (reference) year against which GHQ scores at subsequent annual data collection waves ("T−1", "T+1", "T+2", "T+3") were compared. There is approximately one calendar year between T−1 and T+1, and home relocation might have occurred at any time during this period. The first wave ("T−3") served to establish a consistency of location prior to T−2, ensuring that mental health in the baseline year is not itself a direct reaction to a relocation immediately before the baseline wave. We did not, however, include results from this first wave in our analysis.

Measures. *Mental Health.* Mental health was measured with the short-form twelve item General Health Questionnaire (GHQ), a self-report instrument used to aid diagnosis of disorders such as anxiety and depression.[30] Respondents report how they have felt in the "past few weeks" compared to "usual" for six positive mood states, such as being able to concentrate and make decisions, and six negative mood states, such as

Table 1. Descriptives for the Sample of 594 Individuals Who Moved to Greener Urban Areas[a]

	Time (year) relative to move time (T)				
	T−2	T−1	T+1	T+2	T+3
	mean (SD) or percentage	mean (SD) or percentage	mean (SD) or percentage	mean (SD) or percentage	mean (SD) or percentage
GHQ (inverse)	9.78 (3.21)	9.88 (3.03)	10.10 (3.00)	10.09 (3.09)	10.10 (2.92)
Area Level Variables					
% green space	58.01 (16.06)		74.08 (13.34)		
% water	1.77 (6.58)		1.07 (3.07)		
income deprivation	0.18 (0.13)		0.14 (0.11)		
employment deprivation	11.92 (7.96)		9.71 (6.80)		
education deprivation	25.28 (19.37)		20.29 (19.11)		
crime deprivation	0.32 (0.75)		−0.02 (0.74)		
Individual Level Variables					
age, years	38.87 (15.16)				
age category					
age under 36	56.06%	54.04%	50.51%	45.79%	42.09%
age 36−55	26.60%	28.11%	30.30%	33.84%	36.36%
age over 55	17.34%	17.85%	19.19%	20.37%	21.55%
diploma/degree level qualification	41.08%	41.75%	42.93%	44.61%	45.79%
married/living with partner	74.07%	75.08%	77.78%	78.62%	77.95%
living with children	38.22%	41.41%	45.45%	47.64%	48.65%
log of indexed net adjusted income	10.00 (0.60)	10.05 (0.56)	10.05 (0.66)	10.07 (0.56)	10.08 (0.53)
with work limiting health	10.27%	10.77%	10.77%	11.28%	14.14%
Labor Market Status					
employed/self-employed	72.90%	73.40%	70.03%	69.70%	70.37%
unemployed/long-term sick	5.72%	5.89%	6.40%	5.72%	4.88%
retired	10.61%	10.10%	12.46%	14.48%	14.81%
in education/training	1.52%	0.84%	0.67%	0.84%	0.67%
family carer	9.26%	9.76%	10.44%	9.26%	9.26%
Household Residence Type					
detached house	10.77%	11.62%	26.77%	28.11%	26.77%
semidetached	32.32%	32.49%	37.54%	37.71%	38.55%
terraced	36.36%	35.86%	21.04%	19.53%	20.03%
flat	19.70%	19.53%	13.30%	11.95%	11.95%
other, e.g., bedsit, sheltered	0.84%	0.51%	1.35%	2.69%	2.69%
Household Space					
<1 room/person	6.06%	7.24%	3.70%	4.71%	5.72%
1-<3 rooms/person	81.31%	81.65%	80.64%	81.31%	80.98%
3→3 rooms/person	12.63%	11.11%	15.66%	13.97%	13.30%
Commuting Time					
noncommuters	29.97%	29.29%	31.65%	32.83%	32.49%
15 min and less	31.99%	32.15%	31.99%	29.97%	30.47%
>15−30 min	22.56%	23.40%	19.70%	20.88%	21.72%
>30−50 min	9.09%	8.75%	9.26%	9.43%	8.08%
over 50 min	6.40%	6.40%	7.41%	6.90%	7.24%

[a]Note: T−1 and T+1 are annual data collection time points immediately prior to and succeeding the time of the move to a greener area. T−2 is the annual data collection time point preceding T−1, and T+2 and T+3 are the annual data collection time points succeeding T+1.

feeling under strain and lacking confidence. The dependent variable is GHQ Score, where item responses indicative of distress score 1, and responses indicative of limited or no distress score 0, and these are summed to give a scale score between 0 and 12. Scale scores were reverse coded in the analysis (i.e., Inverse GHQ) so that higher scores represented better mental health.

Green Space. We identified two categories of individual: (a) those who relocated to greener areas, and (b) those who relocated to less green areas, and examined the mental health of these groups before and after their moves; (individuals moving only *within* a residential area are excluded from both samples). The level of greenness around their pre- and postmove homes was derived from the Generalized Land Use Database for England (GLUD),[31] as in earlier research in the UK.[8,16,32,33] GLUD classification of high resolution land parcels was distributed to 32 482 lower-layer super output areas (LSOAs) across England, each encompassing approximately 1500 residents (mean area c.4 km^2). Land use is divided into nine categories: green space; domestic gardens; water; domestic buildings; nondomestic buildings; roads; paths; railways; and other (largely hard standing) and area cover was accurate to approximately 10 m^2 at the time the data were collected (2005). For current purposes we defined "green space" as the

Table 2. Descriptives for the Sample of 470 Individuals Who Moved to Less Green Urban Areas[a]

	time (year) relative to move time (T)				
	T−2	T−1	T+1	T+2	T+3
	mean (SD) or percentage	mean (SD) or percentage	mean (SD) or percentage	mean (SD) or percentage	mean (SD) or percentage
GHQ (inverse)	10.15 (2.93)	9.84 (2.96)	9.99 (3.07)	10.13 (3.02)	10.24 (2.80)
Area Level Variables					
% green space	74.13 (13.67)		59.21 (15.01)		
% water	1.45 (3.40)		2.11 (9.54)		
income deprivation	0.15 (0.11)		0.16 (0.12)		
employment deprivation	10.15 (6.20)		10.68 (7.13)		
education deprivation	21.47 (18.33)		21.74 (19.22)		
crime deprivation	0.08 (0.76)		0.12 (0.79)		
Individual Level Variables					
age, years	37.28 (15.15)				
Age Category					
age under 36	58.30%	54.47%	50.64%	46.81%	43.62
age 36−55	28.51%	31.28%	33.83%	37.02%	38.72
age over 55	13.19%	14.26%	15.53%	16.17%	17.66
diploma/degree level qualification	42.98%	44.89%	46.60%	49.79%	51.91%
married/living with partner	62.55%	62.55%	70.64%	69.36%	69.36%
living with children	34.26%	33.40%	38.51%	40.21%	42.98%
log of indexed net adjusted income	10.03 (0.58)	10.00 (0.89)	10.09 (0.53)	10.09 (0.61)	10.09 (0.61)
with work limiting health	9.79%	9.36%	9.36%	9.36%	10.43%
Labor Market Status					
employed/self-employed	73.40%	75.53%	75.32%	75.96%	75.11%
unemployed/long-term sick	6.81%	5.53%	6.38%	6.17%	5.74%
retired	8.51%	9.36%	9.57%	10.21%	11.06%
in education/training	3.62%	2.13%	0.85%	0.85%	1.06%
family carer	7.66%	7.45%	7.87%	6.81%	7.02%
Household Residence Type					
detached house	22.77%	23.83%	22.34%	22.77%	22.55%
semidetached	34.68%	32.77%	34.04%	32.77%	32.98%
terraced	24.04%	23.83%	26.81%	28.72%	30.21%
flat	17.66%	17.87%	13.83%	13.83%	12.55%
other, e.g., bedsit, sheltered	0.85%	1.70%	2.98%	1.91%	1.70%
Household Space					
<1 room/person	9.36%	8.51%	3.40%	3.40%	4.26%
1-<3 rooms/person	77.02%	75.96%	80.21%	79.79%	79.79%
3→3 rooms/person	13.62%	15.53%	16.38%	16.81%	15.96%
Commuting Time					
noncommuters	25.74%	25.96%	25.96%	26.17%	27.23%
15 min and less	35.32%	34.04%	31.70%	33.40%	31.06%
>15−30 min	22.55%	22.55%	25.32%	23.40%	24.04%
>30−50 min	8.94%	8.72%	9.57%	10.64%	10.64%
over 50 min	7.45%	8.72%	7.45%	6.38%	7.02%

[a]Note: T−1 and T+1 are annual data collection time points immediately prior to and succeeding the time of the move to a less green area. T−2 is the annual data collection time point preceding T−1, and T+2 and T+3 are the annual data collection time points succeeding T+1.

percentage of land cover accounted for by "green space" and "gardens" combined. Excluding gardens produced nearly identical categorization of individuals.

On average, LSOA green space rose from 58.01% (SD = 16.06) to 74.08% (SD = 13.34) for individuals moving to greener areas, and fell from 74.13% (SD = 13.67) to 59.21% (SD = 15.01) for those moving to less green areas. The almost perfectly inverse nature of the average change in the groups is important when comparing the two patterns. The independent variable of interest in our analyses was time in relation to green space change event (home relocation). In contrast to previous work on green space and GHQ using the BHPS,[16] the current analysis does not estimate the effect of a percentage point difference in urban residential green space on GHQ.

Independent Control Variables. Area level covariates included four LSOA socio-economic deprivation statistics derived from the English Indices of Deprivation: income deprivation, based on social benefit data (higher scores indicate less deprivation); employment deprivation, based on unemployment data (higher scores indicate less deprivation); education deprivation, based on school performance, participation in higher education and working age adult qualifications (higher scores indicate less deprivation); and finally the crime rate index, based on the number of reported crimes (higher

Table 3. Fixed Effects Analyses Predicting Inverse GHQ for Urban Residents Moving to Another Urban Area with Higher or Lower Amounts of Greenspace, From Time Relative to Move and Key Area and Individual Level Socio-Demographic Variables

	movers to greener urban areas			movers to less green urban areas		
	coef.	SE	p	coef.	SE	p
Year Relative to Move: Reference 2 Years Premove (T−2)						
1 year premove (T−1)	**0.119**	**0.141**	**.399**	**−0.341**	**0.158**	**.031**
1 year postmove (T+1)	**0.369**	**0.152**	**.015**	**−0.123**	**0.165**	**.456**
2 years postmove (T +2)	**0.378**	**0.158**	**.016**	**0.027**	**0.169**	**.871**
3 years postmove (T +3)	**0.431**	**0.162**	**.008**	**0.163**	**0.175**	**.354**
Area Level Variables						
income	0.764	1.847	0.679	0.968	2.104	0.646
employment	0.004	0.025	0.880	−0.050	0.034	0.142
education	−0.016	0.008	0.036	0.007	0.009	0.441
crime	0.120	0.131	0.357	0.094	0.148	0.527
Individual Level Variables						
Age: Reference 16−35 yrs						
36−55 yrs	−0.275	0.277	0.321	0.398	0.307	0.195
55+ yrs	−0.519	0.573	0.365	0.574	0.644	0.372
diploma/degree level qualified	−0.064	0.465	0.891	−0.644	0.389	0.098
married/living with partner	0.074	0.252	0.770	0.091	0.238	0.703
living with children[a]	−0.288	0.247	0.245	−0.454	0.296	0.126
household income[b]	0.163	0.156	0.298	0.105	0.130	0.417
with work-limiting health[c]	−1.051	0.271	0.000	−0.988	0.339	0.004
Labor Status: Reference Employed/ Self-Employed						
unemployed/ long-term sick	−1.075	0.438	0.014	−1.793	0.483	0.000
retired	−0.329	0.474	0.487	0.204	0.726	0.778
Labor Status: Reference Employed/ Self-Employed						
in education/ training	0.300	0.731	0.681	0.456	0.568	0.423
family carer	−0.556	0.389	0.153	−0.430	0.516	0.405
Household Residence Type: Reference Detached House						
semidetached	0.035	0.193	0.854	0.027	0.205	0.897
terraced	−0.159	0.230	0.489	−0.198	0.240	0.410
flat	0.079	0.273	0.772	0.305	0.282	0.280
other, e.g., bedsit, sheltered	−0.011	0.497	0.983	0.611	0.544	0.262
Household Space[d]: Reference 1-<3 Rooms/ Person						
<1 rooms/ person	0.137	0.286	0.633	0.253	0.337	0.452
3→3rooms/ person	−0.034	0.223	0.879	−0.115	0.236	0.626
Commuting: Reference Noncommuters						
15 min and less	0.147	0.331	0.656	0.522	0.413	0.206
>15−30 min	0.100	0.338	0.768	0.205	0.413	0.620
>30−50 min	0.179	0.373	0.631	0.410	0.453	0.366
over 50 min	0.018	0.396	0.964	0.475	0.480	0.323
constant	8.754	1.616		9.376	1.407	
no. individuals/ observations		594/2970			470/2350	
model R^2		0.05			0.04	

[a]Limited to respondents own children under 16 years old. [b]Log of indexed net household income, adjusted for household composition. [c]Health self-rated as limiting type/duration of work, including in the home; imputed from adjacent wave values for two waves lacking this variable. [d]Excludes kitchens and bathrooms.

scores indicate more deprivation).[34] As with the area green space measure used to define the samples, area level control data were collected in 2004/2005 and distributed to observations in all panel waves.

Individual level control variables were included to account for time-varying factors related to wellbeing:[35] age category; education (being diploma/degree level qualified); marital status (married/living with partner); living with children; household income (log of net household income in the preceding 12 months adjusted for household composition and indexed to January 2010 prices[36]); work-limiting illness (including work in the home); labor market status (employed/self-employed, unemployed, retired, in education/training, family carer); residence type (detached, semidetached, terraced, flat, other); household space (rooms/person ratio); and commuting time (minutes).

Although the BHPS did collect data on an individual's stated motivations for a home relocation, of obvious relevance here, there are several reasons why we do not include this variable in our models. First, the reason given for the "move" between T−1 and T+1 would be the same at all time points and thus, as with gender and ethnicity, there is no heterogeneity within individuals over time and thus move motive cannot be modeled in a fixed effects analysis. Second, an alternative stratification approach, modeling people with different reasons separately, was infeasible because there were 43 separate codes (e.g., "moved in with friends"; "wanted better accommodations") and each individual could select more than one, rendering both very small samples and a lack of clarity about the relative role of different motives. Nevertheless, given the obvious importance of this issue data on move motive are discussed in the Results section to provide some indication as to whether they differed across our two samples.

Analytic Approach. FE regressions were conducted using the xt suite of functions in STATA 12 software. Due to the longitudinal nature of the data, we were able to estimate the effects of time relative to move events while controlling for changes in other circumstances such as income, employment and marital status that may occur at the same time as the move or at other points during the period, and for time-invariant factors such as personality. The basic models can be expressed as:

$$\mathrm{GHQ}_{it} = \alpha_i + \beta \mathrm{year}_{it} + {}_{\gamma}\chi_{it} + {}_{\gamma}Z_{it} + \varepsilon_{it}$$

Where GHQ_{it} is a measure of individual i's GHQ score at time t, α_i is the unobserved individual level component, year_{it} is the year relative to move for individual i, and χ, and Z are sets of individual and area level control variables respectively.

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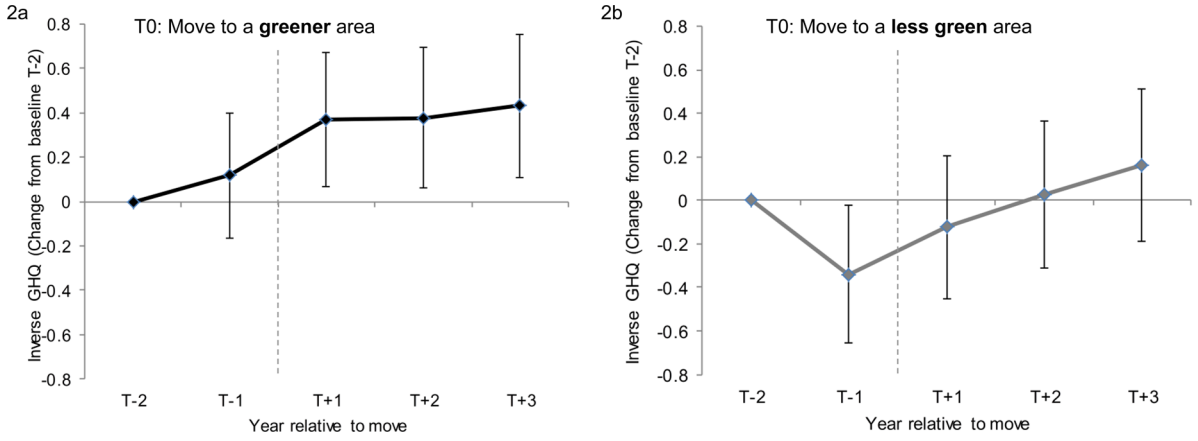

Figure 2. Changes in (inverse) GHQ scores compared to baseline (T−2) following relocations to (a) greener urban areas and (b) less green urban areas (error bars = 95% CIs). Note: T−1 and T+1 are annual data collection time points immediately prior to and succeeding the time of the move to a greener/less green area (T0). T−2 is the annual data collection time point preceding T−1, and T+2 and T+3 are the annual data collection time points succeeding T+1.

Coefficients thus represent the scale point difference in the dependent variable given a scale point increase, or a category change from the reference, in the independent variable, when other independent variables are held constant, controlling for fixed individual differences.

Monitoring mental health for two waves before relocation allowed us to examine potential anticipation effects whereby changes in mental health occur in anticipation of a change (e.g., excitement at moving to a greener area, or sadness at the thought of moving to a more built up area). Such effects have been shown for marriage and divorce, for instance.[17] Monitoring mental health for three waves after relocation enabled us to determine whether changes in mental health reflected processes of adaptation, sensitization or shifting baselines.

RESULTS

Descriptives. There were some differences in the two groups of movers (Tables 1 and 2). For instance, on average, movers to greener areas were slightly older at T−2 (M = 38.87; SD = 15.16) than movers to less green areas (M = 37.28, SD = 15.15), more likely to be married (74.07% vs 62.55%), more likely to be retired (10.61% vs 8.51%), less likely to live in a detached house (10.77% vs 22.77%), and more likely to be noncommuters (29.97% vs 25.74%). Movers to greener areas, who were currently living in less green areas, also had lower mean (inverse) GHQ scores at T−2 (9.78) than movers to less green areas, who were currently living in more green areas, (10.15). This baseline difference reflects previous findings of better mental health in greener urban areas. Intriguingly, mean GHQ for movers to greener areas at T+3 was 10.10, that is, almost identical to mean GHQ at T−2 for movers to less green areas (10.15). Notably, at these points in time both groups were living in areas with near identical mean green space cover (74.08% postmove for the group moving to greener areas, and 74.13% premove for the group moving to less green areas).

There was little change in the means and proportions of some of the control variables over time for both groups (Tables 1 and 2). For example, income, labor market status, household space and commuting time are relatively stable. Other factors did vary over the period. Both groups show increases in the proportions married, highly qualified, living with children and in older age categories, and, among movers to greener areas only, with work-limiting health. House type also shows change over time in both samples. These descriptive trends underline the importance of controlling on these factors in the estimation of the effects of time relative to relocation.

Importantly, move motives were highly similar across the two samples (Supporting Information Table S1). By far the most frequent motive was "larger accommodation" (n = 254), stated by 25.6% of those who moved to a greener area and 21.7% of those who moved to a less green area. Among movers to greener areas, only 4 respondents indicated that area greenness was a reason for the relocation though a few did include factors such as noise (n = 11) and traffic (n = 4), both of which may be related to local area green space. Again, though, these motives were present in similarly low frequencies among movers to less green areas (ns =4, 4, and 2 respectively). Thus not being able to include motives in our regression estimations does not seem to have been an important problem in terms of accounting for the different temporal relationships seen below.

Regression Results. Results of the regressions for both groups of mover are presented in Table 3 and the coefficients for our main variable of interest (i.e., year before and after home relocations) are presented in Figures 2a (movers to greener urban areas) and 2b (movers to less green urban areas). The coefficients for the control variables show that for both samples mental health was lower when individuals had work-limiting health problems and were unemployed. For movers to more green space, mental health was also lower when they lived in areas where the mean level of education was higher.

Movers to greener areas showed no difference in GHQ at T−1 compared to T−2, but then a significant improvement in mental health for each of the three years postmove (Figure 2a). Although the largest improvement was at T+3, (b = 0.43, P = 0.008), which might support a sensitization hypothesis, the improvement in mental health stabilized quickly postmove for the following three years. The data thus best support the immediate shifting baseline hypothesis.

Movers to less green areas showed a significant decrease in mental health at T−1 compared to T−2, (b = −0.34, P = 0.031), but no significant differences for the three years postmove. That is, people have apparently adapted fairly rapidly to living in a less green area (Figure 2b).

DISCUSSION

This study aimed to explore the longitudinal effects of changes in environmental green space on mental health through examination of the impact of home relocation to a greener (or less green) urban area. Previous cross-sectional work suggested mental health is better in greener urban areas,[5,6] and previous estimates from within-individual differences showed that 'on average' mental health improved during years of residence in greener areas.[16] However, this average could reflect a range of different temporal patterns following changes in residential area green space which have different implications for environmental urban design and land use policy. Take the case of relocation to a greener urban area. There may be an initial peak in mental health following the move to a greener area before adaptation takes place and people return to premove levels (i.e., the adaptation hypothesis). Such a process implies time-limited benefits from urban green space development. Alternatively, it may take time to accrue the mental health benefits from moving to a greener area and thus the initial years will show little immediate impact (i.e., the sensitization hypothesis). This implies that initial benefits to mental health from urban greening might be maximized when developments are accompanied by information campaigns, and health or lifestyle promotion work. Finally, the impact might be immediate and sustained, and result in a relatively rapid shift in baseline mental health after a move (i.e., the shifting baseline hypothesis). This scenario implies immediate and potentially long-lasting benefits to local residents from urban green space development. As noted earlier, all three processes have been witnessed following other life changes[17−26] and thus we were unable to predict, a priori, which pattern might explain previous green space related findings.[16]

Our test of these different possibilities suggested that for movers to greener areas, the shifting baseline hypothesis best fit the data (Figure 2a): Mental health improved within a year and stayed approximately the same for the following two years. Results for movers to less green areas were less straightforward (Figure 2b): The predicted decline in mental health for this group occurred before the move and was followed by rapid adaptation to the new circumstances. There are at least two possible interpretations.

First, the anticipation of moving to a less green area may have negatively impacted mental health. Such negative anticipation effects are observed preceding divorce, for instance.[19] Second, declines in mental wellbeing may have precipitated the moves themselves. For instance, it could be that individuals who were becoming increasingly unhappy in greener areas, perhaps due to fewer facilities or job opportunities, decided to move to less green urban areas and once they had done so their mental health improved again. Although possible, move motivations were broadly similar across the two samples and employment related reasons, for instance, were rare among movers to less green space. Thus, at least with the current data, it is difficult to offer move motivation as an explanation for the findings.

Confidence in our results comes from the negative effects on mental health of other life changes included in the analyses such as unemployment and ill-health which have also been demonstrated in previous research.[16,34] The negative relationship observed between area level education and mental health among movers to greener areas may reflect increased stress from living among a new peer group of higher socio-economic status, but this is highly speculative at this stage. The relatively small samples of observations used in the regressions possibly accounts for why some control variables shown in previous work with the BHPS data set to be significantly related to GHQ, such as marital status,[16] were not significant in these estimations.

Study Limitations. First, the constraints of maintaining balanced panels and useable sample sizes restricted analyses to individuals with six years of consecutive data, limiting our ability to follow people's mental health for longer periods of time. Second, relatively small samples made stratification on other variables such as age or income problematic, which leaves open the question of whether different groups vary in their temporal responses to green space change. This issue is particularly pertinent to analysis of move motivations. Although, as noted above, we were unable to include motivations in our models, we did at least control for the main move motivation (accommodation size). Importantly, neither accommodation size nor type was significant in either model, and motivations were broadly similar across the two samples anyway suggesting that differential move motivations are not a simple explanation for the findings. Nonetheless, future research, using the far larger sample from UK's recently initiated Understanding Society panel,[37] will be able to overcome the issue of limited sampling and more fully explore the importance of mover motivations using stratified models.

It is also important to note that FE analysis does not permit inference to a sampled population. Furthermore, while the BHPS sample is representative of adults in the UK, no similar claim can be made about the estimation subsamples used in this research. Of particular interest is the possibility that the representativeness of the samples of movers may be affected by differential attrition. Such differential attrition may be relevant as a possible explanation for the observed absence of sustained declines in mental health among movers to less green space. For instance, it is possible that individuals whose mental health did not recover after T−1 may have been more likely to become nonrespondents during T+1 to T+3. Of course, it is also possible that some individuals experienced declines rather than improvements in mental health following moves to greater green space and were excluded from the estimation sample on the same grounds. Our findings are thus limited to our samples, that is, those individuals for whom we could monitor mental health over six consecutive years. Again, the much larger Understanding Society panel will enable more detailed exploration of these possibilities in the coming years, where different time periods can be explored with more reliability.

Finally, although FE estimation controls for time-invariant individual level heterogeneity (thus reducing estimation bias due to correlation between factors such as heredity and personality, and the predictor variables), the models do not control for all potentially confounding time-varying factors, and thus causality cannot be assumed. Moreover, the available covariates and their operationalization were limited by the available data. For example, while labor market status distinguished employment from unemployment and the other categories, the impact of changes in employment which might occur as a result of redundancy are not accounted for. There are many other potentially stressful and stress reducing life events which are not included in the model and further research is needed to explore these issues directly.

An important example of the limitations of how constructs are operationalized in this work is the fact that cross-sectional

estimates of area level factors (at 2005) were distributed to all waves of data (1991−2008), with no correction for changes within areas over time. We assume this to have very limited impact on our estimations, since comparative differences in environmental and socio-demographic aspects of a residential area at different times are assumed to be slight in comparison to those between different residential areas at the same, or different, times.

We were also unable to examine mechanisms that might explain how green space could improve mental well-being by, for instance, encouraging greater levels of physical activity or promoting better neighborhood relations. Furthermore, it was assumed that area level green space is related to individual exposure: we distributed the community level variable to the individuals in the sample. Thus, again, further work is needed to look at longitudinal trends in potential mechanisms and to better quantify individual level green space exposure among large samples. One possibility would be to compare our findings with those from large-scale "natural experiments"[38] where the mental health and physical activity, for instance, of local populations is monitored before and after changes in local green space (e.g., creation of new parks). Such an approach would also be better able to operationalize individual level green space exposure in terms of both plot size (e.g., comparing one large park vs several smaller parks within a local area) and quality (e.g., design attributes, habitat type, and biodiversity).

Implications. While acknowledging these limitations, our results may nevertheless aid policy makers and urban planners interested in exploring whether "green infrastructure",[39] such as parks and green corridors, produces mental health benefits to local populations. Unlike many other changes in life circumstances, where effects on mental health can be short-lived, moving to a greener urban area was associated with sustained mental health gains. Further work is needed to examine why these effects occur and just how long they may last, and also why the reverse situation was not observed, that is, people who moved to less green areas did not show enduring negative impacts.

■ ASSOCIATED CONTENT

Supporting Information

Additional information as noted in the text. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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