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Housing, neighbourhood and sociodemographic associations with adult levels of physical activity and adiposity: baseline findings from the ENABLE London Study

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Abstract

Objectives: The neighbourhood environment is increasingly shown to be an important correlate of health. We assessed associations between housing tenure, neighbourhood perceptions, sociodemographic factors, and levels of physical activity (PA) and adiposity among adults seeking housing in East Village (formerly London 2012 Olympic/Paralympic Games Athletes' Village).

Setting: Cross-sectional analysis of adults seeking social, intermediate and market-rent housing in East Village.

Participants: 1278 participants took part in the study (58% female). Complete data on adiposity (body mass index [BMI] and fat mass %) were available for 1240 participants (97%); of these a sub-set of 1107 participants (89%) met the inclusion criteria for analyses of accelerometer-based measurements of PA. We examined associations between housing sector sought, neighbourhood perceptions (covariates) and PA and adiposity (dependent variables) adjusted for household clustering, sex, age group, ethnic group, and limiting longstanding illness.

Results: Participants seeking social housing had the fewest steps (8304, 95%CI 7959,8648) and highest BMI (26.0kg/m^2 95%CI 25.5,26.5kg/m^2) compared with those seeking intermediate (steps 9417, 95%CI 9106,9731; BMI 24.8kg/m^2 95%CI 24.4,25.2kg/m^2) or market-rent housing (steps 9313, 95%CI 8858,9768; BMI 24.6kg/m^2 95%CI 24.0,25.2kg/m^2). Those seeking social housing had lower levels of PA (by 19-42%) at weekends vs weekdays, compared with other housing groups. Positive perceptions of neighbourhood quality were associated with higher steps and lower BMI, with differences between social and

intermediate groups reduced by ~10% following adjustment, equivalent to a reduction of 111 for steps and 0.5kg/m^2 for BMI.

Conclusions: The social housing group undertook less PA than other housing sectors, with weekend PA offering the greatest scope for increasing PA, and tackling adiposity in this group. Perceptions of neighbourhood quality were associated with PA and adiposity and reduced differences in steps and BMI between housing sectors. Moving to East Village may provide scope to encourage PA and reduce adiposity amongst the most disadvantaged.

Strengths and limitations of this study

- Large sample with representation of three different aspirational housing groups, providing a wide range of socioeconomic backgrounds
- Objective measurements of physical activity and adiposity outcomes using accelerometry and bioelectrical impedance respectively
- Lower number of participants studied seeking market-rent housing compared with those seeking intermediate or social housing

Keywords

Physical activity; Adiposity; Housing; Perceived neighbourhood environment; ENABLE-London

Introduction

Physical inactivity and adiposity are associated with an increased risk of type 2 diabetes and cardiovascular disease (1-4) and constitute a serious public health problem in the UK and globally (5). Evidence suggests that levels of physical activity (PA) are lower among those who are socioeconomically disadvantaged (6), who experience greater economic, access and health related barriers to being physically active (7). Socioeconomic status is also associated with differences in types of PA, in particular higher socioeconomic status is associated with more vigorous leisure time PA (8). Previous research has found variation in PA by day of the week with studies showing lower levels of activity on Sundays compared with weekdays in young adults (9), parents and their children (10).

There is emerging evidence suggesting that housing tenure is an important determinant of health. In particular, UK-based studies have shown that housing tenure (owner vs. private renter vs. public sector renter) is associated with illness and mortality (15;16). Amongst particular groups including those who are economically inactive or unemployed, housing tenure might provide a better indication of socioeconomic status compared with measures based on occupation or income (11). Indeed, in several studies housing tenure remained associated with health outcomes following adjustment for conventional measures of socioeconomic status such as income or education (12;13). A more nuanced approach is therefore required with respect to measures of socioeconomic status, and they should not be simply regarded as interchangeable (14;15). Despite this, there has been limited research examining the direct effect of housing tenure on PA, and existing evidence is equivocal. Harrison and colleagues found no association between housing tenure and meeting recommended levels of PA among community dwelling healthy adults in the North-East of

England (16). Similarly housing tenure was not associated with self-reported energetic PA among older Australians (17). Ogilvie and colleagues found overall levels of PA to be higher among individuals living in social rented accommodation compared with owner-occupiers (18). The authors suggest that may capture occupational PA levels which are likely to be higher among social renters (18). In contrast, living in private rental accommodation was associated with a greater likelihood of taking up exercise over a 9-year period among men aged 18-49 at baseline, compared with those in local authority accommodation (19).

Housing tenure may affect health and health behaviours in part through characteristics of the home or neighbourhood itself (20;21) or psychological factors such as self-efficacy or self-esteem (22). Social housing estates which are common in the UK may be associated with specific cultures and norms, which in turn shape residents' behaviours (13). Subjective characteristics of the neighbourhood environment including higher perceived access to recreational facilities and shops in local proximity have been shown to be associated with higher levels of PA (23;24). Residents who perceive their neighbourhood more positively, have been shown to have better mental health and are less likely to relocate (25). Conversely, real and perceived crime, has the potential to constrain resident's PA (26). However, a recent systematic review suggested a lack of association between PA and perceptions of safety from crime; highlighting the need for high quality evidence, including prospective studies and natural experiments (27), to examine this issue further. In particular, high quality evidence is needed to understand the potentially multifactorial influence of residential location on health and health behaviours; effects which are likely to extend beyond simple measures of socioeconomic status (27).

The Examining Neighbourhood Activities and Built Living Environments in London (ENABLE London) study is a longitudinal study evaluating how active urban design influences the health and wellbeing of people moving in to the former Athletes' Village of the London 2012 Olympic and Paralympic Games now known as 'East Village' (28). East Village is a new high-density neighbourhood development built on active design principles containing a mix of social housing, intermediate (including affordable rent, shared ownership and shared equity) housing, and market-rent housing. This paper draws on baseline data (prior to any potential move to East Village) to first, examine predictors of PA and adiposity (measured objectively using accelerometry and bioelectrical impedance), including the housing sector to which they are applying and perceptions of their neighbourhood. Second, to examine whether PA patterns across the week vary by housing sector and third, to examine whether adjustment for perceptions of the neighbourhood environment reduce housing sector differences in PA and adiposity.

Methods

Study participants were recruited from those seeking new accommodation in East Village and were classified by the type of housing tenure sought; social, intermediate or market-rent. Current housing status was strongly linked to aspirational housing status, where those seeking social accommodation were currently in social housing or on social housing waiting lists, and those seeking intermediate and market-rent accommodation were largely in privately rented housing. Recruitment of participants in the different housing sectors was carried out between January 2013 and December 2015 in three phases determined by the order of availability of housing in East Village (social, intermediate, and market-rent respectively). Social housing is provided by the local authority or housing association at

subsidised rates. Baseline assessments of participants were carried out in their place of residence before any potential move to East Village. Full details of the recruitment process can be found elsewhere (28).

Independent variables

A team of trained fieldworkers administered self-complete questionnaires on a laptop during home visits. Data on age, sex, self-defined ethnicity, work status, occupation and whether the participant had a limiting longstanding illness or disability (lasting or expected to last at least 12 months) were collected. Participants self-defined as 'White', 'Asian', 'Black', 'Mixed', or 'Other'; the latter two categories were combined for analyses. Socioeconomic status based on occupation was coded using the National Statistics Social-Economic Coding (NS-SEC) to categorise participants into 'higher managerial or professional occupations', 'intermediate occupations', 'routine or manual' (28). An additional 'economically inactive' category included those seeking employment, unable to work due to disability or illness, retired, looking after home and family, and students. We sought information on educational attainment; participants were categorised into "Degree or equivalent / Higher", "Intermediate qualifications" (including A levels and GSCEs), and "Other / None" (including work-based or foreign qualifications). Participants completed questionnaires assessing neighbourhood perceptions. Five items assessed perceived crime (e.g "There is a lot of crime in my neighbourhood"; Cronbach's $\alpha = 0.87$) and six items assessed neighbourhood quality (e.g. "This area is a place I enjoy living in"; Cronbach's $\alpha = 0.78$). Responses on items were summed and scores ranged from -10 to +10 for perceived crime and -12 to +12 for perceived quality, such that positive scores indicate less perceived crime and better neighbourhood quality while negative scores indicate more perceived

crime and poorer quality. The scales were derived following an exploratory factor analysis of 14 questions regarding neighbourhood (Supplementary Table 1).

Dependent variables

Height was measured to the last complete millimetre using a portable stadiometer; weight was measured to the nearest kilogram using a Tanita SC-240 Body Composition Analyzer (Tanita, Tokyo, Japan); body mass index (BMI) was derived as weight(kg)/height(m)^2. The Tanita SC-240 Body Composition Analyzer also measured leg-to-leg bioelectrical impedance from which fat free mass and fat mass were estimated. Fat mass percentage was calculated as fat mass(kg)/weight(kg)*100.

Participants wore a hip-mounted ActiGraph GT3X+ accelerometer during waking hours over a consecutive period of 7 days (ActiGraph LLC, Florida, USA). These accelerometers provided daily measures of steps, counts and time spent in moderate and vigorous PA (MVPA) using established cut-offs. Daily time spent in MVPA both overall and in 10 minute bouts in accordance with UK recommendations for PA (30) were assessed. The cut-point for moderate PA was defined as 5724 counts per minute (31). We excluded any days of recording where the amount of registered time accumulated was below 540 minutes (32). Non-wear periods were defined as a minimum length of 60 minutes, allowing for a 2-minute spike tolerance. Participants with at least one day of recording were retained in analyses. We fitted a multilevel linear model for each outcome to allow for repeated measurements of daily PA, by fitting participant as a random effect and adjusting for day of the week, day order of recording and month as fixed effects. Raw level one residuals were obtained from the model and a within person average value of each outcome variable was obtained by

averaging these raw residuals. The average of these raw residuals for each participant was added to the sample mean for that particular PA variable to derive an unbiased average level of each PA variable for each person.

Statistical analysis

All analyses were carried out using STATA/SE software (Stata/SE 14 for Windows; StataCorp LP, College Station, TX, USA). Outcome variables were inspected for normality and BMI was log transformed due to its skewed distribution. Multilevel linear regression models were fitted, mutually adjusted for housing sector and participant characteristics (sex, age group, ethnic group, and limiting longstanding illness) as fixed effects and a random effect to allow for household clustering. Absolute differences or percentage differences for are presented by sex, age group, ethnic group, limiting longstanding illness and housing sector. Sensitivity analyses examined whether associations remained when the sample was restricted to 931 participants (84%) with at least four days of 540 or more minutes per day of recording.

To assess differences in PA by day of the week as opposed to overall levels of PA we took the following approach. Daily PA data were examined using multilevel models with random effects to allow for multiple days of recording within person and household clustering. An interaction between housing sector and day of the week was fitted and models were adjusted for sex, age group, ethnic group, limiting longstanding illness, day order of recording and month of measurement as fixed effects.

Associations between perceptions of neighbourhood crime and quality with adiposity/PA outcomes were assessed. The effect of adjustment for neighbourhood perceptions in

addition to adjustment for participant characteristics using multilevel models as described above on differences in outcomes between housing sector groups was also examined.

Results

Of 1819 households who consented to initial contact by the study team, 1278 participants from 1006 households (55%) were enrolled in the study and completed a questionnaire. Participation rates for those seeking market-rent and intermediate housing were 58% and 57% respectively and were slightly lower in the social group (52%). Complete data on adiposity were available for 1240 participants (97%); of these a sub-set of 1107 participants (89%) met the inclusion criteria for analyses of objectively measured PA. Participant characteristics (age, sex) and levels of adiposity were similar among those who did and did not provide PA data; however, participants from black and Asian ethnic groups were less likely to provide PA data. Supplementary Table 2 shows participants characteristics at baseline for the 1240 adults with measurements of adiposity at baseline. Those seeking social housing were more likely to be female, of older age, of non-white ethnicity, to have limiting longstanding illness, and be in routine / manual occupations or economically inactive compared to those seeking intermediate or market-rent housing.

Adjusted mean levels of adiposity and PA outcomes by housing sector and participant characteristics are shown in Supplementary Table 3. Table 1 shows housing sector and other participant characteristics associations with adiposity markers (BMI, fat mass %) and objectively measured PA (steps, time spent in MVPA, time spent in MVPA in 10 minute bouts). Participants seeking social housing had markedly higher levels of BMI and fat mass % and markedly lower levels of steps, MVPA and MVPA in 10 minute bouts compared with

those seeking intermediate housing, though there were no differences between those seeking market-rent and intermediate accommodation.

Fat mass % was higher in females than males though there was no difference in BMI (Table 1). BMI and fat mass % were higher among all older age groups compared with 16-24 year olds. Participants of black ethnicity had higher levels of BMI and fat mass % compared with whites; there were no differences in adiposity between Asian or other/mixed ethnic groups and whites. Those with a limiting longstanding illness had higher levels of both BMI and fat mass %. All PA measures were lower among females. Steps and MVPA were slightly higher in 25-34 year olds and steps were also higher among 35-49 year olds compared with 16-24 year olds; however, there were no age group differences for MVPA in 10 minute bouts. Participants of black and Asian ethnicities had lower levels of steps, MVPA and MVPA in 10 minute bouts compared to whites. Participants who reported having a limiting longstanding illness had lower levels of steps and MVPA, but not MVPA in 10 minute bouts. Educational attainment level was not associated with any of the outcomes once housing sector had been adjusted for and adjustment for educational attainment did not materially alter housing sector differences in adiposity or PA outcomes (data available from authors).

Sensitivity analyses for PA outcomes were carried out in 931 participants who wore an ActiGraph for at least four days with at least 540 minutes of recording per day (Supplementary Table 4). There were no differences between market-rent and intermediate groups (consistent with the main analysis presented in Table 1). Differences between social and intermediate groups were broadly similar with the results presented in Table 1 for the main analysis.

Differences in PA variables between housing groups were examined by day of the week to explore whether differences between groups were consistent across the week (Figure 1A-D). Levels of PA (steps (panel A), MVPA (panel B) and MVPA in 10 minute bouts (panel C)) were generally consistent across weekdays (Monday – Friday) among all groups. In the intermediate group, steps were higher on Saturdays and lower on Sundays; MVPA and MVPA in 10 minute bouts were lower on Sundays but there was no difference on Saturdays compared to weekday activity. In the market-rent group, steps, MVPA and MVPA in 10 minute bouts were higher on Saturdays and similar to weekdays on Sundays. In the social group, steps, MVPA and MVPA in 10 minute bouts were on average lower on Saturdays and lower still on Sundays. Registered time (panel D) was lowest on average in the social group during weekdays, decreasing on Saturdays and Sundays. The intermediate and market-rent groups had higher levels of registered time during weekdays compared with the social group which decreased on average on Saturdays and Sundays (despite recording more steps and minutes in MVPA suggesting a higher intensity of activity). Mean levels of steps, MVPA, and MVPA in 10 minute bouts on weekdays and differences on Saturday and Sunday compared to weekdays are shown by housing sector in Supplementary Table 5. The marked differences in activity between weekdays and weekend days in the social group are not explained by differences in registered time (data available from authors).

Associations between perceived neighbourhood quality and crime scales and adiposity and PA outcomes are shown in Table 2, adjusted for the participant characteristics shown in Table 1. All associations between perceived neighbourhood quality and crime and outcome variables were approximately linear and were therefore fitted as continuous variables in the model. In addition, associations between perceived neighbourhood quality and crime and

outcome variables were similar across the three housing groups (all p>0.05). The differences between the highest and lowest quintile of each scale are presented for perceptions of neighbourhood quality (median: 4, IQR: 0, 7) and neighbourhood crime (median: 2, IQR: -1, 5). Participants with the most positive perceptions of neighbourhood quality (highest quintile) had lower BMI, higher steps and recorded longer durations of MVPA compared with those who had the most negative perceptions of neighbourhood quality (lowest quintile). There were no significant associations between perceptions of neighbourhood crime and adiposity or PA.

The effect of adjustment for perceived neighbourhood quality on differences in adiposity and PA between housing sector groups is presented in Table 3. Adjustment for perceptions of neighbourhood quality reduced differences in BMI, fat mass %, steps, MVPA and MVPA in 10 minute bouts between the social and intermediate groups by 10%, 6%, 10%, 10% and 7% respectively. Differences between market-rent and intermediate groups in adiposity and PA variables were not statistically significant before or after adjustment. A larger proportion of the social-intermediate group differences in steps, MVPA and MVPA in 10 minute bouts on weekends was explained by adjustment for perceptions of neighbourhood quality (11%, 16% and 17% respectively) compared to the differences in steps, MVPA and MVPA in 10 minute bouts on weekdays which were reduced by 10%, 8% and 3% respectively.

Discussion

The results of this study showed that participants seeking social housing in East Village had lower levels of PA and higher levels of adiposity compared with those seeking intermediate and market-rent housing, even when adjusted for demographic factors. In the social

housing group, levels of PA were particularly low on weekends compared with weekdays possibly reflecting higher occupational PA and lower leisure time PA; weekday-weekend differences in PA were less marked among those seeking intermediate and market-rent housing. However, the lower registered time at weekends but higher MVPA and steps suggests more intense activity at weekends in the intermediate and market-rent housing groups. These findings may inform targeted interventions to increase PA and reduce adiposity in different socioeconomic groups.

Positive associations between perceived neighbourhood quality and PA and adiposity were also shown. Adjustment for differences in perceived neighbourhood quality reduced differences in PA and adiposity by approximately 10% between social and intermediate housing groups; equivalent to a reduction of 111 for daily steps, 0.5 minutes for MVPA and 0.5kg/m^2 for BMI. However, a larger proportion of the difference in PA was apparent at weekends; equivalent to a reduction of 222 for daily steps and 2.2 minutes for MVPA.

Relation to previous studies

Studies have shown that lower socioeconomic status is associated with lower levels of PA (33;34), and that those from more socially deprived backgrounds have the most barriers to being physically active (7). Previous research examining the role of housing tenure is limited. Findings from this study showed marked differences in PA and adiposity between those seeking social, intermediate and market-rent housing. In particular, lower PA and higher adiposity in participants seeking social housing, a group which comprises a high proportion of people from more socioeconomically disadvantaged backgrounds (28). The higher levels of adiposity in those seeking social housing compared with those seeking intermediate or

market-rent housing is consistent with systematic reviews which have found an association between lower socioeconomic status and higher levels of adiposity, particularly in higher income countries and among women (35). While socioeconomic status is a strong determinant of housing status, to our knowledge this is the first study to explicitly examine housing sector differences in objective PA and adiposity levels. However, it is important to consider more broadly what these aspirational housing sector differences might represent. Related studies have shown that those in social housing are less likely to use active travel compared with owner occupiers (18), and that those in social housing and home owners with a mortgage are more likely to be obese and have higher levels of illness and disability compared to outright home owners, even after adjustment for other socioeconomic status markers (36). These latter findings suggest that the effect of home ownership may be more complex and cannot be simply explained by socioeconomic status. Neighbourhood quality may offer a potential partial explanation for these findings (37). In the present study perceptions of better neighbourhood quality were associated with PA whereas perceptions of crime were not. In contrast, a large UK-based study found that perceptions of feeling safe in the neighbourhood had the largest effect on levels of PA compared with perceptions of leisure facilities, sense of belonging or access to public transport or amenities (38). Another study in the US found that low perceived safety from crime was associated with lower levels of MVPA (39). However, a recent review concluded that higher quality evidence is needed, including prospective studies and natural experiments in areas of wide crime variability, in order to further understand the effect of crime on physical and mental health (27). Moreover, effects of perceived and objective measures of neighbourhood quality may have differing and potentially independent effects on health behaviours including PA (40).

Our findings showed that PA levels were particularly low on the weekend among those seeking social housing, which is consistent with findings from a systematic review which found that leisure-time PA (which may be more likely to occur on weekends) was lower amongst those from lower socioeconomic groups (8). This suggests that low-cost strategies to increase weekend PA may be particularly beneficial to more disadvantaged households. A free community-based program in Bogata Colombia, temporarily closed streets on Sundays to encourage PA amongst more disadvantaged local residents (41). A similar program has been trialled in the United States (42), however the effectiveness, longevity and generalisability of these programs to other socioeconomically deprived areas is yet to be established.

Strengths and limitations

Strengths of this study include the representation of three different aspirational housing groups which provides a wide range of socioeconomic backgrounds. Of those seeking social housing, two-thirds (67%) were currently living in social housing accommodation provided by the local authority or housing association; the remainder were largely currently living in privately rented accommodation with many on social housing waiting lists. Of those seeking intermediate or market-rent accommodation, almost two-thirds were living in privately rented accommodation (both 64%); the remainder were largely living with relatives or friends. The study sample is large with good representation from a 'hard to reach' group of social housing participants. Participation rates were high given the target group, with between 50-60% of those who initially agreed to be contacted taking part in the study. The ActiGraph GT3X+ accelerometer provided validated objective measures of PA (43) and the use of bioelectrical impedance to provide more direct measurements of adiposity including

fat mass %, which may provide a more valid marker of adiposity than BMI, particularly in a multi-ethnic population (44;45). Reassuringly the patterns of PA by sex, ethnic group and health status were consistent with those published previously (46-48). A limitation of the study is the lower number of participants in the market-rent sector compared with the other groups. This was due to restrictions imposed on the study team on the extent and duration of access to potential applicants seeking market-rent accommodation. While the study is longitudinal, these analyses are cross-sectional limiting the degree to which causal inferences can be made. Moreover, there is the possibility of selection amongst study participants, where those who are more active seek to move to East Village, may be more likely to participate in the study and may perceive their environment differently, which may limit the generalisability of the findings to neighbourhoods outside of East London.

Conclusions and future work

The findings presented in this paper suggest that perceived neighbourhood quality is associated with PA and that there are substantial differences in PA and adiposity levels between the three housing groups studied. In particular the very low levels of PA in the social housing group during the weekend could provide a target for intervention to increase levels of PA. Perceptions of neighbourhood quality reduced differences in PA and adiposity between housing sector groups, and the possibility of measuring more objective markers of neighbourhood quality within this study has the potential to explain more (40). The future follow-up of the ENABLE London cohort will allow us to examine whether moving to 'East Village', a neighbourhood designed for healthy active living, will have a positive impact on PA and/or adiposity levels. A major aim of the study is to identify features of the local built environment that increase levels PA which could potentially help to reduce socioeconomic

inequalities in health. It will be of particular interest to determine whether an increase in PA is more apparent in the social housing group whose neighbourhood characteristics should improve. Furthermore, we will be in a position to examine whether any potential effects of the built environment on PA are modified by housing sector type.

Ethical approval

Full ethical approval was obtained from the relevant Multi-Centre Research Ethics Committee (REC Reference 12/LO/1031). All participants provided written informed consent.

Availability of data and material

Further details of the ENABLE London study are available from the study website (http://www.enable.sgul.ac.uk/). The ongoing collection and management of data has been made possible through grant funding from the Medical Research Council and the National Institute of Health Research. We welcome proposals for collaborative projects. For general data sharing inquiries, contact Professor Owen (cowen@sgul.ac.uk).

Competing interests

We declare that we have no competing interests.

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Authorship statement

CGO, ARR, AE, ARC, DL, SC, BG-C, DGC and PHW designed the study and raised funding. BR, ARR, CC, DP and CGO collected data for the study; BR, ARR and CGO enrolled participants. CMN, BR, ARR, CC, DP and CGO undertook data management. CMN analysed the data and wrote the first draft of the report. ARR, BR, AS, DP, ARC, ASP, AE, BG-C, CC, DL, SC, PHW, DGC and CGO critically appraised the manuscript and approved the final draft. CGO is responsible for data integrity.

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Table 1: Associations between participant characteristics and adiposity and physical activity

		Difference/% difference* in adiposity/physical activity														
	n	BMI (kg/m^2)*			Fat mass %			Steps†			Minutes spent in MVPA†			Minutes spent in MVPA in 10 minute bouts†		
Sex																
Male (Ref)	522			-			-			-			-			-
Female	718	-1.16	(-3.17, 0.89)	0.26	11.11	(10.25, 11.98)	<0.0001	-570	(-946, -194)	0.003	-9.29	(-12.21, -6.36)	<0.0001	-4.06	(-6.12, -2.01)	<0.001
Age group																
Age 16-24 (Ref)	269			-			-			-			-			-
Age 25-34	531	6.26	(3.51, 9.08)	<0.0001	3.20	(2.10, 4.31)	<0.0001	502	(11, 992)	0.04	4.03	(0.19, 7.87)	0.04	0.95	(-1.87, 3.77)	0.51
Age 35-49	358	13.35	(10.16, 16.63)	<0.0001	6.36	(5.16, 7.56)	<0.0001	699	(173, 1,224)	0.01	3.85	(-0.25, 7.95)	0.07	-1.11	(-4.05, 1.83)	0.46
Age 50+	82	17.61	(12.55, 22.89)	<0.0001	9.18	(7.33, 11.03)	<0.0001	-9	(-832, 813)	0.98	-5.98	(-12.43, 0.47)	0.07	-2.04	(-6.79, 2.72)	0.40
Ethnic group																
White (Ref)	595			-			-			-			-			-
Black	314	6.23	(3.26, 9.28)	<0.0001	3.63	(2.44, 4.83)	<0.0001	-1,116	(-1,657, -575)	<0.0001	-7.42	(-11.68, -3.17)	<0.001	-6.61	(-9.82, -3.41)	<0.0001
Asian	210	-0.28	(-3.14, 2.67)	0.85	0.02	(-1.20, 1.25)	0.97	-1,409	(-1,972, -845)	<0.0001	-11.46	(-15.89, -7.03)	<0.0001	-8.11	(-11.43, -4.79)	<0.0001
Other/Mixed	121	1.29	(-2.27, 4.98)	0.48	1.04	(-0.47, 2.55)	0.18	-430	(-1,100, 239)	0.21	-4.57	(-9.83, 0.69)	0.09	-3.95	(-7.86, -0.04)	0.05
Limiting illness																
No (Ref)	1087			-			-			-			-			-
Yes	153	4.29	(1.13, 7.55)	0.01	1.63	(0.33, 2.92)	0.01	-1,081	(-1,666, -496)	<0.001	-5.69	(-10.27, -1.12)	0.01	-2.78	(-6.10, 0.55)	0.10
Housing sector																
Social	512	4.96	(2.21, 7.78)	<0.001	2.66	(1.54, 3.78)	<0.0001	-1,125	(-1,629, -620)	<0.0001	-7.53	(-11.50, -3.55)	<0.001	-6.49	(-9.50, -3.48)	<0.0001
Intermediate (Ref)	503			-			-			-			-			-
Market-rent	225	-0.81	(-3.56, 2.02)	0.57	-0.23	(-1.42, 0.96)	0.70	-104	(-633, 424)	0.70	2.26	(-1.90, 6.42)	0.29	2.82	(-0.35, 5.98)	0.08

* Percentage differences are presented for log transformed variables

All differences/% differences are mutually adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level

† Missing data for 133 participants

Table 2: Associations between neighbourhood perceptions scales and adiposity and physical activity

Adiposity (N = 1240)	Difference / % difference in outcome between the highest and lowest quintiles for each neighbourhood factor (95% CI), p-value					
	Perceptions of NH quality scale			Perceptions of NH crime scale		
Body mass index (kg/m^2)*	-3.58	(-6.47, -0.60)	0.02	-2.15	(-5.45, 1.26)	0.21
Fat mass %	-1.23	(-2.51, 0.06)	0.06	-0.76	(-2.20, 0.69)	0.30
Physical activity (N = 1107)						
Steps	-677.49	(-107.99, 1,246.99)	0.02	-63.05	(-713.40, 587.31)	0.85
MVPA (minutes)	4.49	(0.02, 8.95)	0.05	1.06	(-4.03, 6.16)	0.68
MVPA in 10 minute bouts (minutes)	2.67	(-0.63, 5.97)	0.11	2.37	(-1.39, 6.13)	0.22

* % differences are shown for log transformed variables

All differences/% differences are adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level.

Abbreviations: NH, neighbourhood

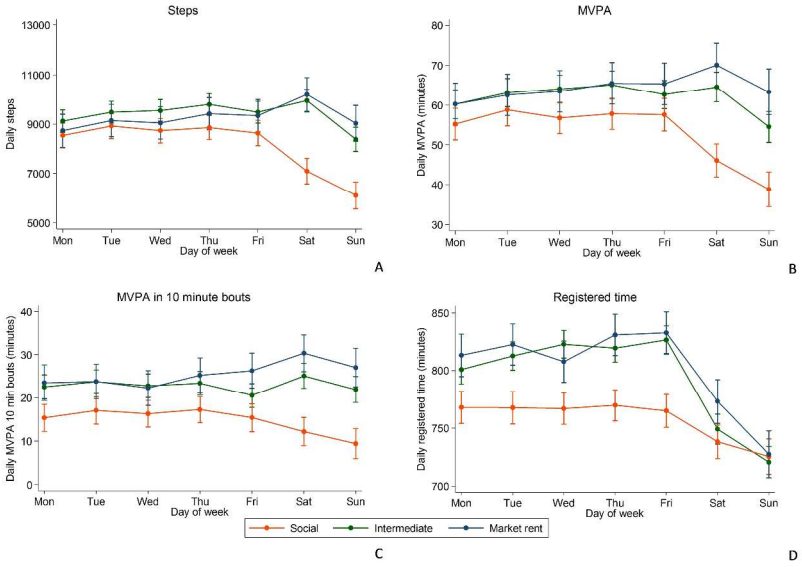
Table 3: Body size, adiposity and physical activity differences between housing sectors: adjustment for perceptions of neighbourhood quality

Adiposity (N = 1240)	Housing sector group	Difference / % difference* compared to intermediate housing group (95% confidence interval), p-value					
		Model 1			Model 2 (Additionally adjusted for neighbourhood quality scale)		
Body mass index (kg/m^2)*	Social	4.96	(2.21, 7.78)	<0.001	4.45	(1.67, 7.31)	0.002
	Intermediate	Reference group					
	Market rent	-0.81	(-3.56, 2.02)	0.57	-0.85	(-3.60, 1.98)	0.55
Fat mass %	Social	2.66	(1.54, 3.78)	<0.0001	2.49	(1.35, 3.63)	<0.0001
	Intermediate	Reference group					
	Market rent	-0.23	(-1.42, 0.96)	0.70	-0.25	(-1.43, 0.94)	0.68
Physical activity (N = 1107)							
Steps	Social	-1,125	(-1,629, -620)	<0.0001	-1,016	(-1,531, -501)	<0.001
	Intermediate	Reference group					
	Market rent	-104	(-633, 424)	0.70	-96	(-624, 431)	0.72
MVPA (minutes)	Social	-7.53	(-11.50, -3.55)	<0.001	-6.76	(-10.81, -2.71)	0.001
	Intermediate	Reference group					
	Market rent	2.26	(-1.90, 6.42)	0.29	2.32	(-1.84, 6.47)	0.27
MVPA in 10 minute bouts (minutes)	Social	-6.49	(-9.50, -3.48)	<0.0001	-6.03	(-9.10, -2.95)	<0.001
	Intermediate	Reference group					
	Market rent	2.82	(-0.35, 5.98)	0.08	2.85	(-0.31, 6.01)	0.08

* % differences are shown for log transformed variables
Model 1 is adjusted for sex, age group, ethnic group, limiting longstanding illness and clustering at household level (random effect)
Model 2: Adjusted for Model 1 plus perceived neighbourhood quality

Figure 1: Daily physical activity by day of the week and housing sector group: N = 6206 days from 1107 participants

Means and 95% confidence intervals are adjusted for sex, age group, ethnic group, limiting longstanding illness, month of recording, day order of recording, day of week, housing sector, an interaction between housing sector and day of week and random effects to allow for multiple days of measurement and clustering of participants within households



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Supplementary material

Supplementary Table 1: Questionnaire items included the factor analysis on perceptions of the neighbourhood

Perceptions of neighbourhood crime items
There is a lot of crime in my neighbourhood.
The level of crime in my neighbourhood makes it unsafe to walk on the streets at night.
There are threatening groups of young people in my neighbourhood.
The level of crime in my neighbourhood makes it unsafe to walk on the streets during the day.
Vandalism, graffiti or deliberate damage to property is a problem in my local area.
Perceptions of neighbourhood quality items
I enjoy walking in my neighbourhood.
This area is a place I enjoy living in.
My neighbourhood is attractive to look at (e.g. there are attractive buildings, green space. Landscaping views).
This area has good leisure things for people like myself, leisure centres or community centres for example.
You often see people out on walks or riding their bicycles in my neighbourhood.
This area has good local transport.
Additional items included in the factor analysis with factor loadings below 0.4 and were therefore not included in the solution
My neighbourhood is generally free from litter.
There is too much traffic in my neighbourhood.
Our neighbourhood streets have good lighting at night.

Participants were asked to select a response from the following for all questionnaire items stated in the table:- Strongly agree, Agree, Neither agree nor disagree, Disagree, Strongly disagree.

Supplementary Table 2: Participant characteristics for 1240 adults with measurements of adiposity at baseline

	Housing sector								
	Social		Intermediate		Private		Total		
	(n = 512)		(n = 503)		(n = 225)		(N = 1240)		p (χ^2)
Sex									
Male	137	(26.8%)	259	(51.5%)	126	(56.0%)	522	(42.1%)	
Female	375	(73.2%)	244	(48.5%)	99	(44.0%)	718	(57.9%)	<0.0001
Age group									
16-24	107	(20.9%)	92	(18.3%)	70	(31.1%)	269	(21.7%)	
25-34	129	(25.2%)	291	(57.9%)	111	(49.3%)	531	(42.8%)	
35-49	233	(45.5%)	102	(20.3%)	23	(10.2%)	358	(28.9%)	
50+	43	(8.4%)	18	(3.6%)	21	(9.3%)	82	(6.6%)	<0.0001
Ethnic group									
White	96	(18.8%)	342	(68.0%)	157	(69.8%)	595	(48.0%)	
Black	245	(47.9%)	53	(10.5%)	16	(7.1%)	314	(25.3%)	
Asian	107	(20.9%)	75	(14.9%)	28	(12.4%)	210	(16.9%)	
Mixed/Other	64	(12.5%)	33	(6.6%)	24	(10.7%)	121	(9.8%)	<0.0001
NS-SEC*									
Higher Managerial / Professional	60	(11.9%)	357	(71.4%)	150	(66.7%)	567	(46.1%)	
Intermediate Occupations	62	(12.3%)	77	(15.4%)	38	(16.9%)	177	(14.4%)	
Routine / Manual	125	(24.8%)	34	(6.8%)	10	(4.4%)	169	(13.7%)	
Economically inactive	258	(51.1%)	32	(6.4%)	27	(12.0%)	317	(25.8%)	<0.0001
Limiting illness									
Yes	102	(19.9%)	40	(8.0%)	11	(4.9%)	153	(12.3%)	
No	410	(80.1%)	463	(92.0%)	214	(95.1%)	1087	(87.7%)	<0.0001

p (χ^2): p-value for Chi-squared test

* 10 responses missing for NS-SEC group

Supplementary Table 3: Mean levels of adiposity and physical activity by participant characteristics

		Mean/Geometric mean* levels adiposity and physical activity									
	n	BMI (kg/m^2)*		Fat mass %		Steps†		Minutes spent in MVPA†		Minutes spent in MVPA in 10 minute bouts†	
Sex											
Male	522	25.4	(25.0, 25.8)	20.4	(19.7, 21.0)	9,279	(8,991, 9,568)	64.8	(62.6, 67.1)	22.8	(21.1, 24.4)
Female	718	25.1	(24.8, 25.5)	31.5	(30.9, 32.0)	8,709	(8,464, 8,954)	55.6	(53.6, 57.5)	18.7	(17.3, 20.1)
Age group											
Age 16-24	269	23.5	(23.0, 24.0)	23.0	(22.1, 23.9)	8,534	(8,136, 8,932)	57.0	(53.9, 60.2)	20.5	(18.2, 22.8)
Age 25-34	531	25.0	(24.6, 25.3)	26.2	(25.5, 26.8)	9,035	(8,744, 9,326)	61.1	(58.8, 63.3)	21.4	(19.7, 23.1)
Age 35-49	358	26.6	(26.1, 27.1)	29.3	(28.5, 30.1)	9,232	(8,879, 9,585)	60.9	(58.1, 63.6)	19.4	(17.3, 21.4)
Age 50+	82	27.6	(26.6, 28.7)	32.2	(30.5, 33.8)	8,525	(7,800, 9,249)	51.1	(45.4, 56.7)	18.4	(14.2, 22.7)
Ethnic group											
White	595	24.9	(24.5, 25.2)	25.8	(25.1, 26.4)	9,491	(9,203, 9,779)	63.6	(61.3, 65.8)	23.7	(22.0, 25.4)
Black	314	26.4	(25.8, 27.0)	29.4	(28.5, 30.3)	8,375	(7,961, 8,789)	56.2	(52.9, 59.4)	17.1	(14.7, 19.6)
Asian	210	24.8	(24.2, 25.4)	25.8	(24.8, 26.8)	8,082	(7,608, 8,556)	52.1	(48.4, 55.8)	15.6	(12.8, 18.4)
Other/Mixed	121	25.2	(24.4, 26.0)	26.8	(25.5, 28.1)	9,060	(8,465, 9,656)	59.0	(54.3, 63.7)	19.8	(16.3, 23.3)
Limiting illness											
No	1087	25.1	(24.9, 25.4)	26.6	(26.1, 27.0)	9,077	(8,877, 9,277)	60.1	(58.6, 61.7)	20.8	(19.6, 21.9)
Yes	153	26.2	(25.5, 27.0)	28.2	(27.0, 29.4)	7,996	(7,447, 8,545)	54.4	(50.1, 58.7)	18.0	(14.8, 21.1)
Housing sector											
Social	512	26.0	(25.6, 26.5)	28.4	(27.6, 29.1)	8,298	(7,953, 8,642)	54.6	(51.8, 57.3)	16.0	(14.0, 18.1)
Intermediate	503	24.8	(24.4, 25.2)	25.7	(25.0, 26.4)	9,422	(9,110, 9,735)	62.1	(59.6, 64.5)	22.5	(20.6, 24.4)
Market-rent	225	24.6	(24.0, 25.2)	25.5	(24.5, 26.5)	9,318	(8,863, 9,773)	64.3	(60.8, 67.9)	25.3	(22.6, 28.1)

* Geometric means are presented for log transformed variables

All means/geometric means are adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level

† Missing data for 133 participants

Supplementary Table 4: Associations between participant characteristics and physical activity variables in participants with at least 4 days of recording of physical activity data

		Difference/% difference* in physical activity variable								
	n	Steps			Minutes spent in MVPA			Minutes spent in MVPA in 10 minute bouts		
Sex										
Male (Ref)	402		-			-			-	
Female	529	-559.1	(-946.6, -171.7)	0.005	-9.73	(-12.75, -6.71)	<0.0001	-4.65	(-6.78, -2.53)	<0.0001
Age group										
Age 16-24 (Ref)	180		-			-			-	
Age 25-34	412	409.9	(-115.7, 935.6)	0.13	3.01	(-1.15, 7.16)	0.16	-0.26	(-3.28, 2.77)	0.87
Age 35-49	276	520.2	(-45.2, 1,085.6)	0.07	2.48	(-1.96, 6.92)	0.27	-2.50	(-5.67, 0.68)	0.12
Age 50+	63	-25.5	(-889.1, 838.1)	0.95	-7.94	(-14.78, -1.10)	0.02	-3.23	(-8.22, 1.76)	0.20
Ethnic group										
White (Ref)	482		-			-			-	
Black	214	-1,213.5	(-1,788.9, -638.0)	<0.0001	-7.08	(-11.67, -2.49)	0.002	-6.46	(-9.87, -3.06)	<0.001
Asian	142	-1,128.3	(-1,718.8, -537.7)	<0.001	-10.29	(-14.99, -5.59)	<0.0001	-7.79	(-11.26, -4.32)	<0.0001
Other/Mixed	93	-581.5	(-1,273.4, 110.4)	0.10	-4.73	(-10.21, 0.76)	0.09	-4.20	(-8.21, -0.18)	0.04
Limiting illness										
No (Ref)	834		-			-			-	
Yes	97	-976.1	(-1,611.5, -340.6)	0.003	-4.63	(-9.63, 0.37)	0.07	-1.98	(-5.59, 1.63)	0.28
Housing sector										
Social	332	-977.5	(-1,514.6, -440.5)	<0.001	-6.87	(-11.16, -2.58)	0.002	-7.21	(-10.40, -4.01)	<0.0001
Intermediate (Ref)	410		-			-			-	
Market-rent	189	-358.7	(-888.8, 171.4)	0.18	0.24	(-4.00, 4.48)	0.91	0.94	(-2.23, 4.12)	0.56

All differences are mutually adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level.

Supplementary Table 5: Physical Activity differences between weekday (Monday-Friday) and weekend (Saturday, Sunday) activity: by housing sector

Physical activity variable (N = 1107)	Housing sector group	Mean (95% CI) weekday (Mon-Fri) activity		Difference in PA outcome compared to weekdays (95% confidence interval), p-value					
				Saturday - weekday			Sunday - weekday		
Steps	Social	8,733	(8,364, 9,103)	-1,643	(-2,078, -1,207)	<0.0001	-2,629	(-3,093, -2,164)	<0.0001
	Intermediate	9,497	(9,178, 9,817)	460	(59, 862)	0.02	-1,104	(-1,528, -680)	<0.0001
	Market-rent	9,146	(8,673, 9,619)	1,055	(467, 1,642)	<0.001	-102	(-734, 531)	0.75
MVPA (minutes)	Social	57.2	(54.3, 60.1)	-11.2	(-14.7, -7.7)	<0.0001	-18.4	(-22.1, -14.7)	<0.0001
	Intermediate	63.1	(60.6, 65.7)	1.5	(-1.8, 4.7)	0.37	-8.5	(-11.9, -5.1)	<0.0001
	Market-rent	63.5	(59.8, 67.3)	6.6	(1.9, 11.3)	0.01	-0.1	(-5.2, 5.0)	0.97
MVPA in 10 minute bouts (minutes)	Social	16.3	(14.0, 18.5)	-4.1	(-6.9, -1.3)	0.004	-6.8	(-9.8, -3.9)	<0.0001
	Intermediate	22.6	(20.7, 24.6)	2.5	(-0.1, 5.1)	0.06	-0.7	(-3.4, 2.0)	0.62
	Market-rent	24.2	(21.3, 27.1)	6.1	(2.4, 9.9)	0.001	2.8	(-1.2, 6.9)	0.17

Means and differences (95% CIs) are adjusted for sex, age group, ethnic group, limiting longstanding illness, month of recording, day order of recording, day of the week, housing sector, an interaction between housing sector and day of week and random effects to allow for multiple days of measurement and clustering of participants within household.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6-7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	6-7
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-8
Bias	9	Describe any efforts to address potential sources of bias	*9*
Study size	10	Explain how the study size was arrived at	6-7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	9-10
		(*c*) Explain how missing data were addressed	N/A
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	9-10
		(*e*) Describe any sensitivity analyses	9
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10-11
		(b) Indicate number of participants with missing data for each variable of interest	10
Outcome data	15*	Report numbers of outcome events or summary measures	10-11
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10-11
		(*b*) Report category boundaries when continuous variables were categorized	11
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11
Discussion			
Key results	18	Summarise key results with reference to study objectives	13-14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16-17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19-20

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Housing, neighbourhood and sociodemographic associations with adult levels of physical activity and adiposity: baseline findings from the ENABLE London Study

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Housing, neighbourhood and sociodemographic associations with adult levels of physical activity and adiposity: baseline findings from the ENABLE London Study

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Tables and figures: 3 tables, 1 figure, 5 supplementary tables

References: 53

Abstract

Objectives: The neighbourhood environment is increasingly shown to be an important correlate of health. We assessed associations between housing tenure, neighbourhood perceptions, sociodemographic factors, and levels of physical activity (PA) and adiposity among adults seeking housing in East Village (formerly London 2012 Olympic/Paralympic Games Athletes' Village).

Setting: Cross-sectional analysis of adults seeking social, intermediate and market-rent housing in East Village.

Participants: 1278 participants took part in the study (58% female). Complete data on adiposity (body mass index [BMI] and fat mass %) were available for 1240 participants (97%); of these a sub-set of 1107 participants (89%) met the inclusion criteria for analyses of accelerometer-based measurements of PA. We examined associations between housing sector sought, neighbourhood perceptions (covariates) and PA and adiposity (dependent variables) adjusted for household clustering, sex, age group, ethnic group, and limiting longstanding illness.

Results: Participants seeking social housing had the fewest daily steps (8304, 95%CI 7959,8648) and highest BMI (26.0kg/m^2 95%CI 25.5,26.5kg/m^2) compared with those seeking intermediate (daily steps 9417, 95%CI 9106,9731; BMI 24.8kg/m^2 95%CI 24.4,25.2kg/m^2) or market-rent housing (daily steps 9313, 95%CI 8858,9768; BMI 24.6kg/m^2 95%CI 24.0,25.2kg/m^2). Those seeking social housing had lower levels of PA (by 19-42%) at weekends vs weekdays, compared with other housing groups. Positive perceptions of neighbourhood quality were associated with higher steps and lower BMI, with differences between social and intermediate groups reduced by ~10% following adjustment, equivalent to a reduction of 111 for steps and 0.5kg/m^2 for BMI.

Conclusions: The social housing group undertook less PA than other housing sectors, with weekend PA offering the greatest scope for increasing PA, and tackling adiposity in this group. Perceptions of neighbourhood quality were associated with PA and adiposity and reduced differences in steps and BMI between housing sectors. Interventions to encourage physical activity at weekends and improve neighbourhood quality, especially amongst the most disadvantaged, may provide scope to reduce inequalities in health behaviour.

Strengths and limitations of this study

- Large sample with representation of three different aspirational housing groups, providing a wide range of socioeconomic backgrounds
- Objective measurements of physical activity and adiposity outcomes using accelerometry and bioelectrical impedance respectively
- Lower number of participants studied seeking market-rent housing compared with those seeking intermediate or social housing

Keywords

Physical activity; Adiposity; Housing; Perceived neighbourhood environment; ENABLE-London

Introduction

Physical inactivity and adiposity are associated with an increased risk of type 2 diabetes and cardiovascular disease (1-4) and constitute a serious public health problem in the UK and globally (5). Evidence suggests that levels of physical activity (PA) are lower among those who are socioeconomically disadvantaged (6), who experience greater economic, access and health related barriers to being physically active (7). Socioeconomic status is also associated with differences in types of PA, in particular higher socioeconomic status is associated with more vigorous leisure time PA (8). Previous research has found variation in PA by day of the week with studies showing lower levels of activity on Sundays compared with weekdays in young adults (9), parents and their children (10).

There is emerging evidence suggesting that housing tenure is an important determinant of health. In particular, UK-based studies have shown that housing tenure (owner vs. private renter vs. public sector renter) is associated with illness and mortality (15;16). Amongst particular groups including those who are economically inactive or unemployed, housing tenure might provide a better indication of socioeconomic status compared with measures based on occupation or income (11). Indeed, in several studies housing tenure remained associated with health outcomes following adjustment for conventional measures of socioeconomic status such as income or education (12;13). A more nuanced approach is therefore required with respect to measures of socioeconomic status, and they should not be simply regarded as interchangeable (14;15). Despite this, there has been limited research examining the direct effect of housing tenure on PA, and existing evidence is equivocal. Harrison and colleagues found no association between housing tenure and meeting recommended levels of PA among community dwelling healthy adults in the North-East of

England (16). Similarly housing tenure was not associated with self-reported energetic PA among older Australians (17). Ogilvie and colleagues found overall levels of PA to be higher among individuals living in social housing compared with owner-occupiers (18). The authors suggest that may capture occupational PA levels which are likely to be higher among those in social housing (18). In contrast, living in private rental accommodation was associated with a greater likelihood of taking up exercise over a 9-year period among men aged 18-49 at baseline, compared with those in local authority accommodation (19).

Housing tenure may affect health and health behaviours in part through characteristics of the home or neighbourhood itself (20;21) or psychological factors such as self-efficacy or self-esteem (22). Social housing estates which are common in the UK may be associated with specific cultures and norms, which in turn shape residents' behaviours (13). Subjective characteristics of the neighbourhood environment including higher perceived access to recreational facilities and shops in local proximity have been shown to be associated with higher levels of PA (23;24). Residents who perceive their neighbourhood more positively, have been shown to have better mental health and are less likely to relocate (25). Conversely, real and perceived crime, has the potential to constrain residents' PA (26). However, a recent systematic review suggested a lack of association between PA and perceptions of safety from crime; highlighting the need for high quality evidence, including prospective studies and natural experiments (27), to examine this issue further. In particular, high quality evidence is needed to understand the potentially multifactorial influence of residential location on health and health behaviours; effects which are likely to extend beyond simple measures of socioeconomic status (27).

The Examining Neighbourhood Activities and Built Living Environments in London (ENABLE London) study is a longitudinal study evaluating how active urban design influences the health and wellbeing of people moving into the former Athletes' Village of the London 2012 Olympic and Paralympic Games now known as 'East Village' (28). East Village is a new high-density neighbourhood development built on active design principles containing a mix of social housing, intermediate (including affordable rent, shared ownership and shared equity) housing, and market-rent housing. This paper draws on baseline data (prior to any potential move to East Village) to first, examine predictors of PA and adiposity (measured objectively using accelerometry and bioelectrical impedance), including the housing sector to which they are applying and perceptions of their neighbourhood. Second, to examine whether PA patterns across the week vary by housing sector and third, to examine whether adjustment for perceptions of the neighbourhood environment reduce housing sector differences in PA and adiposity.

Methods

Study participants were recruited from those seeking or who had applied for new accommodation in East Village and were classified by the type of housing tenure sought based on level of income; i.e. social, intermediate or market-rent. The inclusion criteria was broad and included anyone interested / applying for single or multiple occupancy accommodation in East Village. There was no explicit exclusion criteria; adults of any age, gender, ethnic group, with or without handicap, were invited to participate. Current housing status was strongly linked to aspirational housing status, where those seeking social accommodation were currently in social housing or on social housing waiting lists, and those seeking intermediate and market-rent accommodation were largely in privately rented

housing. Recruitment of participants in the different housing sectors was carried out between January 2013 and December 2015 in three phases determined by the order of availability of housing in East Village (social, intermediate, and market-rent respectively). Those applying for social housing in East Village were initially recruited between January 2013 and May 2014, households seeking intermediate accommodation between July 2013 and November 2014 and those seeking market rent accommodation between September 2014 and December 2015. Recruitment processes for those applying for social housing were slightly different compared with other housing sectors. The East Thames Group housing association was primarily responsible for recruiting participants in social housing, whereas the ENABLE London team (in association with Triathlon Homes and Get Living London) recruited participants from the other housing sectors (28). Aspirational housing tenure is integral to the design of ENABLE London, and we have shown that this provides a clear socioeconomic marker of study participants. For example, those seeking social housing in East Village are more likely to be unemployed, less educated and more likely to represent ethnic minorities (a classic marker of socioeconomic vulnerability), compared to those seeking affordable and market-rent accommodation (29). We have also shown key differences in mental health and well-being between housing groups, where those seeking social housing were more likely to be depressed, anxious and have poorer well-being, compared to other housing groups (30). Moreover, this is entirely consistent with earlier studies which found that both current housing tenure and aspirational housing tenure are associated with a variety of health outcomes, including mental health and measures of general health (31;32).

Baseline assessments of participants were carried out in their place of residence before any potential move to East Village. Full details of the recruitment process can be found elsewhere (28).

Independent variables

A team of trained fieldworkers administered self-complete questionnaires on a laptop during home visits. Data on age, sex, self-defined ethnicity, work status, occupation and whether the participant had a limiting longstanding illness or disability (lasting or expected to last at least 12 months) were collected. Participants self-defined as 'White', 'Asian', 'Black', 'Mixed', or 'Other'; the latter two categories were combined for analyses. Socioeconomic status based on occupation was coded using the National Statistics Social-Economic Coding (NS-SEC) to categorise participants into 'higher managerial or professional occupations', 'intermediate occupations', 'routine or manual' (33). An additional 'economically inactive' category included those seeking employment, unable to work due to disability or illness, retired, looking after home and family, and students. We sought information on educational attainment; participants were categorised into "Degree or equivalent / Higher", "Intermediate qualifications" (including A levels and GSCEs), and "Other / None" (including work-based or foreign qualifications). Participants completed questionnaires assessing neighbourhood perceptions (30). Five items assessed perceived crime (e.g., "There is a lot of crime in my neighbourhood"; Cronbach's $\alpha = 0.87$) and six items assessed neighbourhood quality (e.g. "This area is a place I enjoy living in"; Cronbach's $\alpha = 0.78$). Responses on items were summed and scores ranged from -10 to +10 for perceived crime and -12 to +12 for perceived quality, such that positive scores indicate less perceived crime and better neighbourhood quality while negative scores indicate more

perceived crime and poorer quality. The scales were derived following an exploratory factor analysis of 14 questions regarding neighbourhood (Supplementary Table 1).

Dependent variables

Height was measured to the last complete millimetre using a portable stadiometer; weight was measured to the nearest kilogram using a Tanita SC-240 Body Composition Analyzer (Tanita, Tokyo, Japan); body mass index (BMI) was derived as weight(kg)/height(m)^2. The Tanita SC-240 Body Composition Analyzer also measured leg-to-leg bioelectrical impedance from which fat free mass and fat mass were estimated. Fat mass percentage was calculated as fat mass (kg)/weight (kg)*100.

Participants wore a hip-mounted ActiGraph GT3X+ accelerometer during waking hours over a consecutive period of 7 days (ActiGraph LLC, Florida, USA). These accelerometers provided daily measures of steps, counts and time spent in moderate and vigorous PA (MVPA) using established cut-offs. Daily time spent in MVPA both overall and in ≥10 minute bouts in accordance with UK recommendations for PA (34) were assessed. The cut-point for moderate PA was defined as ≥1952 counts per minute (35). We excluded any days of recording where the amount of registered time accumulated was below 540 minutes (36). Non-wear periods were defined as a minimum length of 60 minutes, allowing for a 2-minute spike tolerance. Participants with at least one day of recording were retained in analyses. We fitted a multilevel linear model for each outcome to allow for repeated measurements of daily PA, by fitting participant as a random effect and adjusting for day of the week, day order of recording and month as fixed effects. Raw level one residuals were obtained from the model and a within person average value of each outcome variable was obtained by

averaging these raw residuals. The average of these raw residuals for each participant was added to the sample mean for that particular PA variable to derive an unbiased average level of each PA variable for each person.

Statistical analysis

All analyses were carried out using STATA/SE software (Stata/SE 14 for Windows; StataCorp LP, College Station, TX, USA). Outcome variables were inspected for normality and BMI was log transformed due to its skewed distribution. Multilevel linear regression models were fitted, mutually adjusted for housing sector and participant characteristics (sex, age group, ethnic group, and limiting longstanding illness) as fixed effects, with a random effect to allow for household clustering. Residuals did not show departure from linearity, suggesting that the model assumptions were appropriate. Absolute differences or percentage differences for log transformed outcomes (i.e. BMI) are presented by sex, age group, ethnic group, limiting longstanding illness and housing sector. Sensitivity analyses examined whether associations remained when the sample was restricted to 931 participants (84%) with at least four days of 540 or more minutes per day of recording.

To assess differences in PA by day of the week as opposed to overall levels of PA we took the following approach. Daily PA data were examined using multilevel models with random effects to allow for multiple days of recording within person and household clustering. An interaction between housing sector and day of the week was fitted and models were adjusted for sex, age group, ethnic group, limiting longstanding illness, day order of recording and month of measurement as fixed effects.

The associations between neighbourhood perception scales and adiposity and PA outcomes were examined. Each of the neighbourhood quality and crime scores were included in the models as quintiles, to examine the differences in outcomes between the top and bottom quintile. Finally, the effect of adjustment for neighbourhood perception on differences in adiposity and PA between housing sectors was examined. If associations between outcomes and neighbourhood perceptions appeared linear, models examining housing sector differences were additionally adjusted for neighbourhood perceptions as a continuous variable.

Patient and Public Involvement

The ENABLE London study was developed in partnership with a network of both local and regional stakeholders identified through our collaborator links to agencies, involved with the design, planning and management of large-scale accommodation developments. Locally these included local authorities (particularly Newham) and a number of housing associations, in particular Triathlon Homes, a partner organisation of housing associations, which manages social and intermediate homes in East Village. Participants have been involved in the study from an early stage to ensure assessments and participation remain relevant and enjoyable, to ensure the continued significance and potential generalisability of the work.

Results

Of 1819 households who agreed to be contacted by the study team in order to receive further information about the ENABLE London study, 1278 adults from 1006 households (55%) participated in the study and completed a questionnaire. Participation rates for those

seeking market-rent and intermediate housing were 58% and 57% respectively and were slightly lower in the social group (52%). Complete data on adiposity were available for 1240 participants (97%); of these a sub-set of 1107 participants (89%) met the inclusion criteria for analyses of objectively measured PA. Participant characteristics (age, sex) and levels of adiposity were similar among those who did and did not provide PA data; however, participants from black and Asian ethnic groups were less likely to provide PA data. Supplementary Table 2 shows participants characteristics at baseline for the 1240 adults with measurements of adiposity at baseline. Those seeking social housing were more likely to be female, of older age, of non-white ethnicity, to have limiting longstanding illness, and be in routine / manual occupations or economically inactive compared to those seeking intermediate or market-rent housing.

Adjusted mean levels of adiposity and PA outcomes by housing sector and participant characteristics are shown in Supplementary Table 3. Table 1 shows housing sector and other participant characteristics associations with BMI and fat mass %, and objectively measured PA (steps, time spent in MVPA, time spent in MVPA in ≥10 minute bouts). Participants seeking social housing had markedly higher levels of BMI and fat mass % and markedly lower levels of steps, MVPA and MVPA in ≥10 minute bouts compared with those seeking intermediate housing, though there were no differences between those seeking market-rent and intermediate accommodation.

Fat mass % was higher in females than males though there was no difference in BMI (Table 1). BMI and fat mass % were higher among all older age groups compared with 16-24 year olds. Participants of black ethnicity had higher levels of BMI and fat mass % compared with

whites; there were no differences in BMI and fat mass % between Asian or other/mixed ethnic groups and whites. Those with a limiting longstanding illness had higher levels of both BMI and fat mass %. All PA measures were lower among females. Steps and MVPA were slightly higher in 25-34 year olds and steps were also higher among 35-49 year olds compared with 16-24 year olds; however, there were no age group differences for MVPA in ≥10 minute bouts. Participants of black and Asian ethnicities had lower levels of steps, MVPA and MVPA in ≥10 minute bouts compared to whites. Participants who reported having a limiting longstanding illness had lower levels of steps and MVPA, but not MVPA in ≥10 minute bouts. Educational attainment level was not associated with any of the outcomes once housing sector had been adjusted for and adjustment for educational attainment did not materially alter housing sector differences in adiposity or PA outcomes (data available from authors).

Sensitivity analyses for PA outcomes were carried out in 931 participants who wore an ActiGraph for at least four days with at least 540 minutes of recording per day (Supplementary Table 4). There were no differences between market-rent and intermediate groups (consistent with the main analysis presented in Table 1). Differences between social and intermediate groups were broadly similar with the results presented in Table 1 for the main analysis.

Differences in PA variables between housing groups were examined by day of the week to explore whether differences between groups were consistent across the week (Figure 1A-D). Levels of PA (steps (panel A), MVPA (panel B) and MVPA in ≥10 minute bouts (panel C)) were generally consistent across weekdays (Monday – Friday) among all groups. In the

intermediate group, steps were higher on Saturdays and lower on Sundays; MVPA and MVPA in ≥10 minute bouts were lower on Sundays but there was no difference on Saturdays compared to weekday activity. In the market-rent group, steps, MVPA and MVPA in ≥10 minute bouts were higher on Saturdays and similar to weekdays on Sundays. In the social group, steps, MVPA and MVPA in ≥10 minute bouts were on average lower on Saturdays and lower still on Sundays. Registered time (panel D) was lowest on average in the social group during weekdays, decreasing on Saturdays and Sundays. The intermediate and market-rent groups had higher levels of registered time during weekdays compared with the social group which decreased on average on Saturdays and Sundays (despite recording more steps and minutes in MVPA suggesting a higher intensity of activity). Mean levels of steps, MVPA, and MVPA in ≥10 minute bouts on weekdays and differences on Saturday and Sunday compared to weekdays are shown by housing sector in Supplementary Table 5. The marked differences in activity between weekdays and weekend days in the social group are not explained by differences in registered time (data available from authors).

Associations between perceived neighbourhood quality and crime scales and adiposity and PA outcomes are shown in Table 2, adjusted for the participant characteristics shown in Table 1. Participants with the most positive perceptions of neighbourhood quality (highest quintile) had lower BMI, higher steps and recorded longer durations of MVPA compared with those who had the most negative perceptions of neighbourhood quality (lowest quintile). There were no significant associations between perceptions of neighbourhood crime and adiposity or PA.

The effect of adjustment for perceived neighbourhood quality on differences in adiposity and PA between housing sector groups is presented in Table 3. All associations between perceived neighbourhood quality and crime and outcome variables were approximately linear and were therefore fitted as continuous variables in the model. In addition, associations between perceived neighbourhood quality and crime and outcome variables were similar across the three housing groups (all $p>0.05$). Adjustment for perceptions of neighbourhood quality reduced differences in BMI, fat mass %, steps, MVPA and MVPA in ≥10 minute bouts between the social and intermediate groups by 10%, 6%, 10%, 10% and 7% respectively. Differences between market-rent and intermediate groups in adiposity and PA variables were not statistically significant before or after adjustment. A larger proportion of the social-intermediate group differences in steps, MVPA and MVPA in ≥10 minute bouts on weekends was explained by adjustment for perceptions of neighbourhood quality (10%, 16% and 16% respectively) compared to the differences in steps, MVPA and MVPA in ≥10 minute bouts on weekdays which were reduced by 10%, 8% and 3% respectively (data not shown).

Discussion

The results of this study showed that participants seeking social housing in East Village had lower levels of PA and higher levels of BMI and fat mass % compared with those seeking intermediate and market-rent housing, even when adjusted for demographic factors. In the social housing group, levels of PA were particularly low on weekends compared with weekdays possibly reflecting higher occupational PA and lower leisure time PA; weekday-weekend differences in PA were less marked among those seeking intermediate and market-rent housing. However, the lower registered time at weekends but higher MVPA

and steps suggests more intense activity at weekends in the intermediate and market-rent housing groups. These findings may inform targeted interventions to increase PA and reduce adiposity in different socioeconomic groups.

Positive associations between perceived neighbourhood quality and PA, BMI and fat mass % were also shown. Adjustment for differences in perceived neighbourhood quality reduced differences in PA and BMI by approximately 10% between social and intermediate housing groups; equivalent to a reduction of 111 for daily steps, 0.5 minutes for MVPA and 0.5kg/m^2 for BMI. However, a larger proportion of the difference in PA was apparent at weekends; equivalent to a reduction of 222 for daily steps and 2.2 minutes for MVPA.

Relation to previous studies

Studies have shown that lower socioeconomic status is associated with lower levels of PA (37;38), and that those from more socially deprived backgrounds have the most barriers to being physically active (7). Previous research examining the role of housing tenure is limited. Findings from this study showed marked differences in PA and adiposity between those seeking social, intermediate and market-rent housing. In particular, lower PA and higher adiposity in participants seeking social housing, a group which comprises a high proportion of people from more socioeconomically disadvantaged backgrounds (28). The higher levels of BMI and fat mass % in those seeking social housing compared with those seeking intermediate or market-rent housing is consistent with systematic reviews which have found an association between lower socioeconomic status and higher levels of adiposity, particularly in higher income countries and among women (39). While socioeconomic status is a strong determinant of housing status, to our knowledge this is the first study to

explicitly examine housing sector differences in objective PA and markers of adiposity levels (i.e. BMI and fat mass %). However, it is important to consider more broadly what these aspirational housing sector differences might represent. Related studies have shown that those in social housing are less likely to use active travel compared with owner occupiers (18), and that those in social housing and home owners with a mortgage are more likely to be obese and have higher levels of illness and disability compared to outright home owners, even after adjustment for other socioeconomic status markers (40). These latter findings suggest that the effect of home ownership may be more complex and cannot be simply explained by socioeconomic status. Neighbourhood quality may offer a potential partial explanation for these findings (41). In the present study perceptions of better neighbourhood quality were associated with PA whereas perceptions of crime were not. In contrast, a large UK-based study found that perceptions of feeling safe in the neighbourhood had the largest effect on levels of PA compared with perceptions of leisure facilities, sense of belonging or access to public transport or amenities (42). Another study in the US found that low perceived safety from crime was associated with lower levels of MVPA (43). However, a recent review concluded that higher quality evidence is needed, including prospective studies and natural experiments in areas of wide crime variability, in order to further understand the effect of crime on physical and mental health (27). Moreover, previous work has suggested that objective and perceived measures of the built environment correlate differently with physical activity levels, suggesting that these measures are assessing different dimensions of the built environment which relate differently to health behaviour (44).

Our findings showed that PA levels were particularly low on the weekend among those seeking social housing, which is consistent with findings from a systematic review which found that leisure-time PA (which may be more likely to occur on weekends) was lower amongst those from lower socioeconomic groups (8). This suggests that low-cost strategies to increase weekend PA may be particularly beneficial to more disadvantaged households. A free community-based program in Bogata Colombia, temporarily closed streets on Sundays to encourage PA amongst more disadvantaged local residents (45). A similar program has been trialled in the United States (46), however the effectiveness, longevity and generalisability of these programs to other socioeconomically deprived areas is yet to be established.

Strengths and limitations

Strengths of this study include the representation of three different aspirational housing groups which provides a wide range of socioeconomic backgrounds. Of those seeking social housing, two-thirds (67%) were currently living in social housing accommodation provided by the local authority or housing association; the remainder were largely currently living in privately rented accommodation with many on social housing waiting lists. Of those seeking intermediate or market-rent accommodation, almost two-thirds were living in privately rented accommodation (both 64%); the remainder were largely living with relatives or friends. The study sample is large with good representation from a 'hard to reach' group of social housing participants. Participation rates were high given the target group, with between 50-60% of those who initially agreed to be contacted taking part in the study. The ActiGraph GT3X+ accelerometer provided validated objective measures of PA (47) and the use of bioelectrical impedance to provide more direct measurements of adiposity including

fat mass %, which may provide a more valid marker of adiposity than BMI, particularly in a multi-ethnic population (48;49). Reassuringly the patterns of PA by sex, ethnic group and health status were consistent with those published previously (50-52). A limitation of the study is the lower number of participants in the market-rent sector compared with the other groups. This was due to restrictions imposed on the study team on the extent and duration of access to potential applicants seeking market-rent accommodation. While the study is longitudinal, these analyses are cross-sectional limiting the degree to which causal inferences can be made. Moreover, there is the possibility of selection amongst study participants, where those who are more active seek to move to East Village, may be more likely to participate in the study and may perceive their environment differently, which may limit the generalisability of the findings to neighbourhoods outside of East London.

Conclusions and future work

The findings presented in this paper suggest that perceived neighbourhood quality is associated with meaningful differences in PA and markers of adiposity. Differences in steps (680 steps) and BMI (3.6kg/m²) between the lowest and highest quintiles of perceived neighbourhood quality should be considered in the context of an average 10,000 steps per day, where a 5% increase (500 steps) would be a worthwhile population level increase and a 5kg/m² increase in BMI is associated with a 31% increase in all-cause mortality (53). Hence, improvements in neighbourhood quality could be associated with health benefits of public health importance. There were also substantial differences in PA, BMI and fat mass % between the three housing groups studied. In particular the very low levels of PA in the social housing group during the weekend could provide a target for intervention to increase levels of PA; again these differences should be considered in relation to 500 steps per day,

which can be considered as an increase of population importance. Perceptions of neighbourhood quality reduced differences in PA and adiposity between housing sector groups, and the possibility of measuring more objective markers of neighbourhood quality within this study has the potential to explain more (44). The future follow-up of the ENABLE London cohort will allow us to examine whether moving to 'East Village', a neighbourhood designed for healthy active living, will have a positive impact on PA and/or adiposity levels. A major aim of the study is to identify features of the local built environment that increase levels of PA which could potentially help to reduce socioeconomic inequalities in health. It will be of particular interest to determine whether an increase in PA is more apparent in the social housing group whose neighbourhood characteristics should improve. Furthermore, we will be in a position to examine whether any potential effects of the built environment on PA are modified by housing sector type.

Ethical approval

Full ethical approval was obtained from the relevant Multi-Centre Research Ethics Committee (REC Reference 12/LO/1031). All participants provided written informed consent.

Data sharing statement

Further details of the ENABLE London study are available from the study website (http://www.enable.sgul.ac.uk/). The ongoing collection and management of data has been made possible through grant funding from the Medical Research Council and the National Institute of Health Research. We welcome proposals for collaborative projects. For general data sharing inquiries, contact Professor Owen (cowen@sgul.ac.uk).

Competing interests

We declare that we have no competing interests.

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Authorship statement

CGO, ARR, AE, ARC, DL, SC, BG-C, DGC and PHW designed the study and raised funding. BR, ARR, CC, DP and CGO collected data for the study; BR, ARR and CGO enrolled participants. CMN, BR, ESL, ARR, CC, DP and CGO undertook data management. CMN, ESL analysed the data; CMN wrote the first draft of the report. ARR, BR, ESL, AS, DP, ARC, ASP, AE, BG-C, CC, DL, SC, PHW, DGC and CGO critically appraised the manuscript and approved the final draft. CGO is responsible for data integrity.

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Table 1: Associations between adiposity and physical activity outcomes and patient characteristics

		Difference or % difference* in adiposity/physical activity (95% CI), p-value														
	n	BMI (kg/m^2)*			Fat mass %			Daily steps†			Daily minutes spent in MVPA†			Daily minutes spent in MVPA in ≥10 minute bouts†		
Sex																
Male (Ref)	522			-			-			-			-			-
Female	718	-1.2	(-3.2, 0.9)	0.26	11.1	(10.3, 12.0)	<0.0001	-570	(-946, -194)	0.003	-9.3	(-12.2, -6.4)	<0.0001	-4.1	(-6.1, -2.0)	<0.001
Age group																
Age 16-24 (Ref)	269			-			-			-			-			-
Age 25-34	531	6.3	(3.5, 9.1)	<0.0001	3.2	(2.1, 4.3)	<0.0001	502	(11, 992)	0.04	4.0	(0.2, 7.9)	0.04	1.0	(-1.9, 3.8)	0.51
Age 35-49	358	13.4	(10.2, 16.6)	<0.0001	6.4	(5.2, 7.6)	<0.0001	699	(173, 1224)	0.01	3.9	(-0.2, 8.0)	0.07	-1.1	(-4.0, 1.8)	0.46
Age 50+	82	17.6	(12.6, 22.9)	<0.0001	9.2	(7.3, 11.0)	<0.0001	-9	(-832, 813)	0.98	-6.0	(-12.4, 0.5)	0.07	-2.0	(-6.8, 2.7)	0.40
Ethnic group																
White (Ref)	595			-			-			-			-			-
Black	314	6.2	(3.3, 9.3)	<0.0001	3.6	(2.4, 4.8)	<0.0001	-1116	(-1657, -575)	<0.0001	-7.4	(-11.7, -3.2)	<0.001	-6.6	(-9.8, -3.4)	<0.0001
Asian	210	-0.3	(-3.1, 2.7)	0.85	0.02	(-1.2, 1.3)	0.97	-1409	(-1972, -845)	<0.0001	-11.5	(-15.9, -7.0)	<0.0001	-8.1	(-11.4, -4.8)	<0.0001
Other/Mixed	121	1.3	(-2.3, 5.0)	0.48	1.0	(-0.5, 2.5)	0.18	-430	(-1100, 239)	0.21	-4.6	(-9.8, 0.7)	0.09	-4.0	(-7.9, -0.04)	0.05
Limiting illness																
No (Ref)	1087			-			-			-			-			-
Yes	153	4.3	(1.1, 7.5)	0.01	1.6	(0.3, 2.9)	0.01	-1081	(-1666, -496)	<0.001	-5.7	(-10.3, -1.1)	0.01	-2.8	(-6.1, 0.5)	0.10
Housing sector																
Social	512	5.0	(2.2, 7.8)	<0.001	2.7	(1.5, 3.8)	<0.0001	-1125	(-1629, -620)	<0.0001	-7.5	(-11.5, -3.6)	<0.001	-6.5	(-9.5, -3.5)	<0.0001
Intermediate (Ref)	503			-			-			-			-			-
Market-rent	225	-0.8	(-3.6, 2.0)	0.57	-0.2	(-1.4, 1.0)	0.70	-104	(-633, 424)	0.70	2.3	(-1.9, 6.4)	0.29	2.8	(-0.3, 6.0)	0.08

* Percentage differences are presented for BMI, which was log-transformed for analysis

All differences and % differences are mutually adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level

† Missing data for 133 participants

MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

Table 2: Associations between adiposity and physical activity outcomes and neighbourhood perceptions scales

	Difference or % difference* in outcome between the highest and lowest quintiles for each neighbourhood scale (95% CI), p-value					
	Perceptions of NH quality			Perceptions of NH crime		
Adiposity (N = 1240)						
Body mass index (kg/m^2)*	-3.6	(-6.5, -0.6)	0.02	-2.1	(-5.4, 1.3)	0.21
Fat mass %	-1.2	(-2.5, 0.06)	0.06	-0.8	(-2.2, 0.7)	0.30
Physical activity (N = 1107)						
Daily steps	677	(108, 1247)	0.02	-63	(-713, 587)	0.85
Daily MVPA (minutes)	4.5	(0.02, 9.0)	0.05	1.1	(-4.0, 6.2)	0.68
Daily MVPA in ≥10 minute bouts (minutes)	2.7	(-0.6, 6.0)	0.11	2.4	(-1.4, 6.1)	0.22

* Percentage differences are presented for BMI, which was log-transformed for analysis
All differences and % differences are adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level.
Abbreviations: NH, neighbourhood
MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

Table 3: Adiposity and physical activity differences between housing sectors: adjustment for perceptions of neighbourhood quality

	Housing sector group	Difference or % difference* compared to intermediate housing group (95% confidence interval), p-value					
		Model 1			Model 2 (Additionally adjusted for neighbourhood quality scale)		
Adiposity (N = 1240)							
Body mass index (kg/m^2)*	Social	5.0	(2.2, 7.8)	<0.001	4.5	(1.7, 7.3)	0.002
	Intermediate	Reference group					
	Market rent	-0.8	(-3.6, 2.0)	0.57	-0.9	(-3.6, 2.0)	0.55
Fat mass %	Social	2.7	(1.5, 3.8)	<0.0001	2.5	(1.4, 3.6)	<0.0001
	Intermediate	Reference group					
	Market rent	-0.2	(-1.4, 1.0)	0.70	-0.2	(-1.4, 0.9)	0.68
Physical activity (N = 1107)							
Daily steps	Social	-1125	(-1629, -620)	<0.0001	-1016	(-1531, -501)	<0.001
	Intermediate	Reference group					
	Market rent	-104	(-633, 424)	0.70	-96	(-624, 431)	0.72
Daily MVPA (minutes)	Social	-7.5	(-11.5, -3.6)	<0.001	-6.8	(-10.8, -2.7)	0.001
	Intermediate	Reference group					
	Market rent	2.3	(-1.9, 6.4)	0.29	2.3	(-1.8, 6.5)	0.27
Daily MVPA in ≥10 minute bouts (minutes)	Social	-6.5	(-9.5, -3.5)	<0.0001	-6.0	(-9.1, -3.0)	<0.001
	Intermediate	Reference group					
	Market rent	2.8	(-0.3, 6.0)	0.08	2.8	(-0.3, 6.0)	0.08

* Percentage differences are presented for BMI, which was log-transformed for analysis
Model 1: Adjusted for sex, age group, ethnic group, limiting longstanding illness and clustering at household level (random effect)
Model 2: Adjusted as Model 1 plus neighbourhood quality scale (added as a continuous variable)
MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

Figure 1: Daily physical activity by day of the week and housing sector group: N = 6206 days from 1107 participants

Means and 95% confidence intervals are adjusted for sex, age group, ethnic group, limiting longstanding illness, month of recording, day order of recording, day of week, housing sector, an interaction between housing sector and day of week and random effects to allow for multiple days of measurement and clustering of participants within households

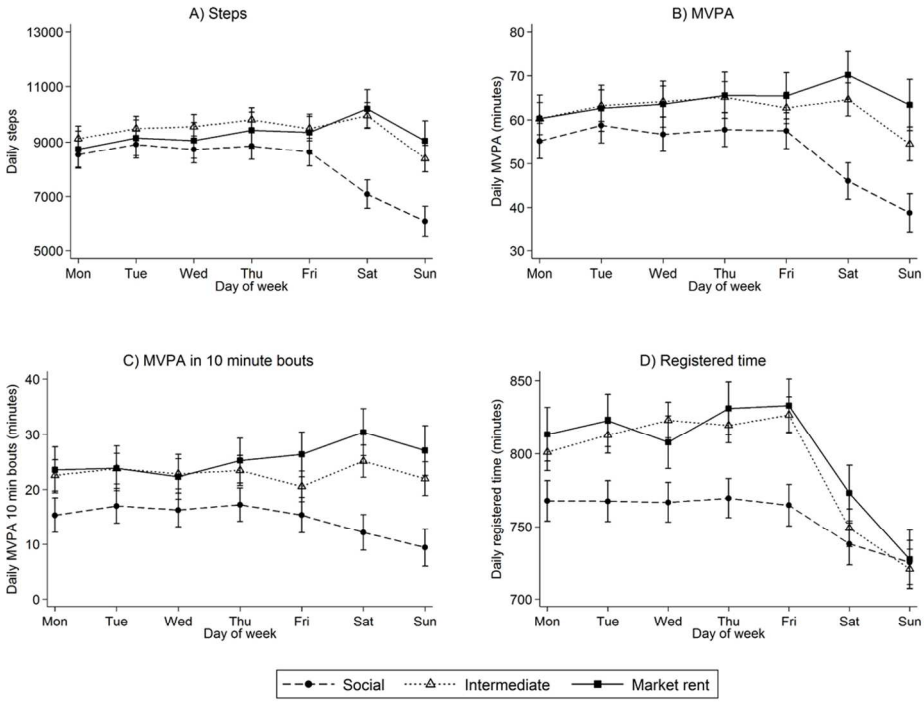

Figure 1: Daily physical activity by day of the week and housing sector group: N = 6206 days from 1107 participants

119x90mm (300 x 300 DPI)

Supplementary Table 1: Questionnaire items included in the factor analysis on perceptions of the neighbourhood

Perceptions of neighbourhood crime items
There is a lot of crime in my neighbourhood.
The level of crime in my neighbourhood makes it unsafe to walk on the streets at night.
There are threatening groups of young people in my neighbourhood.
The level of crime in my neighbourhood makes it unsafe to walk on the streets during the day.
Vandalism, graffiti or deliberate damage to property is a problem in my local area.
Perceptions of neighbourhood quality items
I enjoy walking in my neighbourhood.
This area is a place I enjoy living in.
My neighbourhood is attractive to look at (e.g. there are attractive buildings, green space. Landscaping views).
This area has good leisure things for people like myself, leisure centres or community centres for example.
You often see people out on walks or riding their bicycles in my neighbourhood.
This area has good local transport.
Additional items included in the factor analysis with factor loadings below 0.4 and were therefore not included in the solution
My neighbourhood is generally free from litter.
There is too much traffic in my neighbourhood.
Our neighbourhood streets have good lighting at night.

Participants were asked to select a response from the following for all questionnaire items stated in the table: Strongly agree, Agree, Neither agree nor disagree, Disagree, Strongly disagree

Supplementary Table 2: Participant characteristics for 1240 adults with measurements of adiposity at baseline

	Housing sector								
	Social		Intermediate		Market rent		Total		
	(n = 512)		(n = 503)		(n = 225)		(N = 1240)		p (χ^2)
Sex									
Male	137	(26.8%)	259	(51.5%)	126	(56.0%)	522	(42.1%)	
Female	375	(73.2%)	244	(48.5%)	99	(44.0%)	718	(57.9%)	<0.0001
Age group									
16-24	107	(20.9%)	92	(18.3%)	70	(31.1%)	269	(21.7%)	
25-34	129	(25.2%)	291	(57.9%)	111	(49.3%)	531	(42.8%)	
35-49	233	(45.5%)	102	(20.3%)	23	(10.2%)	358	(28.9%)	
50+	43	(8.4%)	18	(3.6%)	21	(9.3%)	82	(6.6%)	<0.0001
Ethnic group									
White	96	(18.8%)	342	(68.0%)	157	(69.8%)	595	(48.0%)	
Black	245	(47.9%)	53	(10.5%)	16	(7.1%)	314	(25.3%)	
Asian	107	(20.9%)	75	(14.9%)	28	(12.4%)	210	(16.9%)	
Mixed/Other	64	(12.5%)	33	(6.6%)	24	(10.7%)	121	(9.8%)	<0.0001
NS-SEC*									
Higher Managerial / Professional	60	(11.9%)	357	(71.4%)	150	(66.7%)	567	(46.1%)	
Intermediate Occupations	62	(12.3%)	77	(15.4%)	38	(16.9%)	177	(14.4%)	
Routine / Manual	125	(24.8%)	34	(6.8%)	10	(4.4%)	169	(13.7%)	
Economically inactive	258	(51.1%)	32	(6.4%)	27	(12.0%)	317	(25.8%)	<0.0001
Limiting illness									
Yes	102	(19.9%)	40	(8.0%)	11	(4.9%)	153	(12.3%)	
No	410	(80.1%)	463	(92.0%)	214	(95.1%)	1087	(87.7%)	<0.0001

p (χ^2): p-value for Chi-squared test

* 10 responses missing for NS-SEC group

Supplementary Table 3: Mean levels of adiposity and physical activity by patient characteristics

		Mean/Geometric mean* levels adiposity and physical activity (95% confidence intervals)									
	n	BMI (kg/m^2)*		Fat mass %		Daily steps†		Daily minutes of MVPA†		Daily minutes of MVPA in ≥10 minute bouts†	
Sex											
Male	522	25.4	(25.0, 25.8)	20.4	(19.7, 21.0)	9279	(8991, 9568)	64.8	(62.6, 67.1)	22.8	(21.1, 24.4)
Female	718	25.1	(24.8, 25.5)	31.5	(30.9, 32.0)	8709	(8464, 8954)	55.6	(53.6, 57.5)	18.7	(17.3, 20.1)
Age group											
Age 16-24	269	23.5	(23.0, 24.0)	23.0	(22.1, 23.9)	8534	(8136, 8932)	57.0	(53.9, 60.2)	20.5	(18.2, 22.8)
Age 25-34	531	25.0	(24.6, 25.3)	26.2	(25.5, 26.8)	9035	(8744, 9326)	61.1	(58.8, 63.3)	21.4	(19.7, 23.1)
Age 35-49	358	26.6	(26.1, 27.1)	29.3	(28.5, 30.1)	9232	(8879, 9585)	60.9	(58.1, 63.6)	19.4	(17.3, 21.4)
Age 50+	82	27.6	(26.6, 28.7)	32.2	(30.5, 33.8)	8525	(7800, 9249)	51.1	(45.4, 56.7)	18.4	(14.2, 22.7)
Ethnic group											
White	595	24.9	(24.5, 25.2)	25.8	(25.1, 26.4)	9491	(9203, 9779)	63.6	(61.3, 65.8)	23.7	(22.0, 25.4)
Black	314	26.4	(25.8, 27.0)	29.4	(28.5, 30.3)	8375	(7961, 8789)	56.2	(52.9, 59.4)	17.1	(14.7, 19.6)
Asian	210	24.8	(24.2, 25.4)	25.8	(24.8, 26.8)	8082	(7608, 8556)	52.1	(48.4, 55.8)	15.6	(12.8, 18.4)
Other/Mixed	121	25.2	(24.4, 26.0)	26.8	(25.5, 28.1)	9060	(8465, 9656)	59.0	(54.3, 63.7)	19.8	(16.3, 23.3)
Limiting illness											
No	1087	25.1	(24.9, 25.4)	26.6	(26.1, 27.0)	9077	(8877, 9277)	60.1	(58.6, 61.7)	20.8	(19.6, 21.9)
Yes	153	26.2	(25.5, 27.0)	28.2	(27.0, 29.4)	7996	(7447, 8545)	54.4	(50.1, 58.7)	18.0	(14.8, 21.1)
Housing sector											
Social	512	26.0	(25.6, 26.5)	28.4	(27.6, 29.1)	8298	(7953, 8642)	54.6	(51.8, 57.3)	16.0	(14.0, 18.1)
Intermediate	503	24.8	(24.4, 25.2)	25.7	(25.0, 26.4)	9422	(9110, 9735)	62.1	(59.6, 64.5)	22.5	(20.6, 24.4)
Market-rent	225	24.6	(24.0, 25.2)	25.5	(24.5, 26.5)	9318	(8863, 9773)	64.3	(60.8, 67.9)	25.3	(22.6, 28.1)

* Geometric means are presented for BMI

All means/geometric means are adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level.

† Data missing for 133 participants for average daily steps, MVPA and MVPA in bouts

Supplementary Table 4: Associations between participant characteristics and physical activity variables in participants with at least 4 days of recording of physical activity data

		Difference or % difference* in physical activity variable (95% confidence interval), p-value								
	n	Daily steps			Daily minutes spent in MVPA			Daily minutes spent in MVPA in ≥10 minute bouts		
Sex										
Male (Ref)	402		-			-			-	
Female	529	-559	(-947, -172)	0.005	-9.7	(-12.7, -6.7)	<0.0001	-4.7	(-6.8, -2.5)	<0.0001
Age group										
Age 16-24 (Ref)	180		-			-			-	
Age 25-34	412	410	(-116, 936)	0.13	3.0	(-1.2, 7.2)	0.16	-0.3	(-3.3, 2.8)	0.87
Age 35-49	276	520	(-45, 1086)	0.07	2.5	(-2.0, 6.9)	0.27	-2.5	(-5.7, 0.7)	0.12
Age 50+	63	-25	(-889, 838)	0.95	-7.9	(-14.8, -1.1)	0.02	-3.2	(-8.2, 1.8)	0.20
Ethnic group										
White (Ref)	482		-			-			-	
Black	214	-1213	(-1789, -638)	<0.0001	-7.1	(-11.7, -2.5)	0.002	-6.5	(-9.9, -3.1)	<0.001
Asian	142	-1128	(-1719, -538)	<0.001	-10.3	(-15.0, -5.6)	<0.0001	-7.8	(-11.3, -4.3)	<0.0001
Other/Mixed	93	-582	(-1273, 110)	0.10	-4.7	(-10.2, 0.8)	0.09	-4.2	(-8.2, -0.2)	0.04
Limiting illness										
No (Ref)	834		-			-			-	
Yes	97	-976	(-1612, -341)	0.003	-4.6	(-9.6, 0.4)	0.07	-2.0	(-5.6, 1.6)	0.28
Housing sector										
Social	332	-978	(-1515, -440)	<0.001	-6.9	(-11.2, -2.6)	0.002	-7.2	(-10.4, -4.0)	<0.0001
Intermediate (Ref)	410		-			-			-	
Market-rent	189	-359	(-889, 171)	0.185	0.2	(-4.0, 4.3)	0.91	0.9	(-2.2, 4.1)	0.56

All differences are mutually adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level.
MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

Supplementary Table 5: Physical activity differences between weekday (Monday-Friday) and weekend (Saturday, Sunday) activity by housing sector.

Physical activity variable (N = 1107)	Housing sector group	Mean (95% CI) weekday (Mon-Fri) activity		Difference in PA outcome compared to weekdays (95% confidence interval), p-value					
				Saturday - weekday			Sunday - weekday		
Daily steps	Social	8733	(8364, 9103)	-1643	(-2078, -1207)	<0.0001	-2629	(-3093, -2164)	<0.0001
	Intermediate	9497	(9178, 9817)	460	(59, 862)	0.02	-1104	(-1528, -680)	<0.0001
	Market-rent	9146	(8673, 9619)	1055	(467, 1642)	<0.001	-102	(-734, 531)	0.75
MVPA (minutes)	Social	57.2	(54.3, 60.1)	-11.2	(-14.7, -7.7)	<0.0001	-18.4	(-22.1, -14.7)	<0.0001
	Intermediate	63.1	(60.6, 65.7)	1.5	(-1.8, 4.7)	0.37	-8.5	(-11.9, -5.1)	<0.0001
	Market-rent	63.5	(59.8, 67.3)	6.6	(1.9, 11.3)	0.01	-0.1	(-5.2, 5.0)	0.97
MVPA in ≥10 minute bouts (minutes)	Social	16.3	(14.0, 18.5)	-4.1	(-6.9, -1.3)	0.004	-6.8	(-9.8, -3.9)	<0.0001
	Intermediate	22.6	(20.7, 24.6)	2.5	(-0.06, 5.1)	0.06	-0.7	(-3.4, 2.0)	0.62
	Market-rent	24.2	(21.3, 27.1)	6.1	(2.4, 9.9)	0.001	2.8	(-1.2, 6.9)	0.17

Means and differences (95% confidence intervals) are adjusted for sex, age group, ethnic group, limiting longstanding illness, month of recording, day of the week, housing sector, an interaction between housing sector and day of week, and random effects to allow for multiple days of measurement and clustering of participants within household.

MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

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Housing, neighbourhood and sociodemographic associations with adult levels of physical activity and adiposity: baseline findings from the ENABLE London Study

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Abstract

Objectives: The neighbourhood environment is increasingly shown to be an important correlate of health. We assessed associations between housing tenure, neighbourhood perceptions, sociodemographic factors, and levels of physical activity (PA) and adiposity among adults seeking housing in East Village (formerly London 2012 Olympic/Paralympic Games Athletes' Village).

Setting: Cross-sectional analysis of adults seeking social, intermediate and market-rent housing in East Village.

Participants: 1278 participants took part in the study (58% female). Complete data on adiposity (body mass index [BMI] and fat mass %) were available for 1240 participants (97%); of these a sub-set of 1107 participants (89%) met the inclusion criteria for analyses of accelerometer-based measurements of PA. We examined associations between housing sector sought, neighbourhood perceptions (covariates) and PA and adiposity (dependent variables) adjusted for household clustering, sex, age group, ethnic group, and limiting longstanding illness.

Results: Participants seeking social housing had the fewest daily steps (8304, 95%CI 7959,8648) and highest BMI (26.0kg/m^2 95%CI 25.5,26.5kg/m^2) compared with those seeking intermediate (daily steps 9417, 95%CI 9106,9731; BMI 24.8kg/m^2 95%CI 24.4,25.2kg/m^2) or market-rent housing (daily steps 9313, 95%CI 8858,9768; BMI 24.6kg/m^2 95%CI 24.0,25.2kg/m^2). Those seeking social housing had lower levels of PA (by 19-42%) at weekends vs weekdays, compared with other housing groups. Positive perceptions of neighbourhood quality were associated with higher steps and lower BMI, with differences between social and intermediate groups reduced by ~10% following adjustment, equivalent to a reduction of 111 for steps and 0.5kg/m^2 for BMI.

Conclusions: The social housing group undertook less PA than other housing sectors, with weekend PA offering the greatest scope for increasing PA, and tackling adiposity in this group. Perceptions of neighbourhood quality were associated with PA and adiposity and reduced differences in steps and BMI between housing sectors. Interventions to encourage physical activity at weekends and improve neighbourhood quality, especially amongst the most disadvantaged, may provide scope to reduce inequalities in health behaviour.

Strengths and limitations of this study

- Large sample with representation of three different aspirational housing groups, providing a wide range of socioeconomic backgrounds
- Objective measurements of physical activity and adiposity outcomes using accelerometry and bioelectrical impedance respectively
- Lower number of participants studied seeking market-rent housing compared with those seeking intermediate or social housing

Keywords

Physical activity; Adiposity; Housing; Perceived neighbourhood environment; ENABLE-London

Introduction

Physical inactivity and adiposity are associated with an increased risk of type 2 diabetes and cardiovascular disease (1-4) and constitute a serious public health problem in the UK and globally (5). Evidence suggests that levels of physical activity (PA) are lower among those who are socioeconomically disadvantaged (6), who experience greater economic, access and health related barriers to being physically active (7). Socioeconomic status is also associated with differences in types of PA, in particular higher socioeconomic status is associated with more vigorous leisure time PA (8). Previous research has found variation in PA by day of the week with studies showing lower levels of activity on Sundays compared with weekdays in young adults (9), parents and their children (10).

There is emerging evidence suggesting that housing tenure is an important determinant of health. In particular, UK-based studies have shown that housing tenure (owner vs. private renter vs. public sector renter) is associated with poor health (11;12). Amongst particular groups including those who are economically inactive or unemployed, housing tenure might provide a better indication of socioeconomic status compared with measures based on occupation or income (13). Indeed, in several studies housing tenure remained associated with health outcomes following adjustment for conventional measures of socioeconomic status such as income or education (11;14). A more nuanced approach is therefore required with respect to measures of socioeconomic status, and they should not be simply regarded as interchangeable (12;15). Despite this, there has been limited research examining the direct effect of housing tenure on PA, and existing evidence is equivocal. Harrison and colleagues found no association between housing tenure and meeting recommended levels of PA among community dwelling healthy adults in the North-East of England (16). Similarly

housing tenure was not associated with self-reported energetic PA among older Australians (17). Ogilvie and colleagues found overall levels of PA to be higher among individuals living in social housing compared with owner-occupiers (18). The authors suggest that may capture occupational PA levels which are likely to be higher among those in social housing (18). In contrast, living in private rental accommodation was associated with a greater likelihood of taking up exercise over a 9-year period among men aged 18-49 at baseline, compared with those in local authority accommodation (19).

Housing tenure may affect health and health behaviours in part through characteristics of the home or neighbourhood itself (20;21) or psychological factors such as self-efficacy or self-esteem (22). Social housing estates which are common in the UK may be associated with specific cultures and norms, which in turn shape residents' behaviours (11). Subjective characteristics of the neighbourhood environment including higher perceived access to recreational facilities and shops in local proximity have been shown to be associated with higher levels of PA (23;24). Residents who perceive their neighbourhood more positively, have been shown to have better mental health and are less likely to relocate (25). Conversely, real and perceived crime, has the potential to constrain residents' PA (26). However, a recent systematic review suggested a lack of association between PA and perceptions of safety from crime; highlighting the need for high quality evidence, including prospective studies and natural experiments (27), to examine this issue further. In particular, high quality evidence is needed to understand the potentially multifactorial influence of residential location on health and health behaviours; effects which are likely to extend beyond simple measures of socioeconomic status (27).

The Examining Neighbourhood Activities and Built Living Environments in London (ENABLE London) study is a longitudinal study evaluating how active urban design influences the health and wellbeing of people moving into the former Athletes' Village of the London 2012 Olympic and Paralympic Games now known as 'East Village' (28). East Village is a new high-density neighbourhood development built on active design principles containing a mix of social housing, intermediate (including affordable rent, shared ownership and shared equity) housing, and market-rent housing. This paper draws on baseline data (prior to any potential move to East Village) to first, examine predictors of PA and adiposity (measured objectively using accelerometry and bioelectrical impedance), including the housing sector to which they are applying and perceptions of their neighbourhood. Second, to examine whether PA patterns across the week vary by housing sector and third, to examine whether adjustment for perceptions of the neighbourhood environment reduce housing sector differences in PA and adiposity.

Methods

Study participants were recruited from those seeking or who had applied for new accommodation in East Village and were classified by the type of housing tenure sought based on level of income; i.e. social, intermediate or market-rent. The inclusion criteria was broad and included anyone interested / applying for single or multiple occupancy accommodation in East Village. There was no explicit exclusion criteria; adults of any age, gender, ethnic group, with or without handicap, were invited to participate. Current housing status was strongly linked to aspirational housing status, where those seeking social accommodation were currently in social housing or on social housing waiting lists, and those seeking intermediate and market-rent accommodation were largely in privately rented

housing. Recruitment of participants in the different housing sectors was carried out between January 2013 and December 2015 in three phases determined by the order of availability of housing in East Village (social, intermediate, and market-rent respectively). Those applying for social housing in East Village were initially recruited between January 2013 and May 2014, households seeking intermediate accommodation between July 2013 and November 2014 and those seeking market rent accommodation between September 2014 and December 2015. Recruitment processes for those applying for social housing were slightly different compared with other housing sectors. The East Thames Group housing association was primarily responsible for recruiting participants in social housing, whereas the ENABLE London team (in association with Triathlon Homes and Get Living London) recruited participants from the other housing sectors (28). Aspirational housing tenure is integral to the design of ENABLE London, and we have shown that this provides a clear socioeconomic marker of study participants. For example, those seeking social housing in East Village are more likely to be unemployed, less educated and more likely to represent ethnic minorities (a classic marker of socioeconomic vulnerability), compared to those seeking affordable and market-rent accommodation (28). We have also shown key differences in mental health and well-being between housing groups, where those seeking social housing were more likely to be depressed, anxious and have poorer well-being, compared to other housing groups (29). Moreover, this is entirely consistent with earlier studies which found that both current housing tenure and aspirational housing tenure are associated with a variety of health outcomes, including mental health and measures of general health (20;30).

Baseline assessments of participants were carried out in their place of residence before any potential move to East Village. Full details of the recruitment process can be found elsewhere (28).

Independent variables

A team of trained fieldworkers administered self-complete questionnaires on a laptop during home visits. Data on age, sex, self-defined ethnicity, work status, occupation and whether the participant had a limiting longstanding illness or disability (lasting or expected to last at least 12 months) were collected. Participants self-defined as 'White', 'Asian', 'Black', 'Mixed', or 'Other'; the latter two categories were combined for analyses. Socioeconomic status based on occupation was coded using the National Statistics Social-Economic Coding (NS-SEC) to categorise participants into 'higher managerial or professional occupations', 'intermediate occupations', 'routine or manual' (31). An additional 'economically inactive' category included those seeking employment, unable to work due to disability or illness, retired, looking after home and family, and students. We sought information on educational attainment; participants were categorised into "Degree or equivalent / Higher", "Intermediate qualifications" (including A levels and GSCEs), and "Other / None" (including work-based or foreign qualifications). Participants completed questionnaires assessing neighbourhood perceptions (29). Five items assessed perceived crime (e.g., "There is a lot of crime in my neighbourhood"; Cronbach's $\alpha = 0.87$) and six items assessed neighbourhood quality (e.g. "This area is a place I enjoy living in"; Cronbach's $\alpha = 0.78$). Responses on items were summed and scores ranged from -10 to +10 for perceived crime and -12 to +12 for perceived quality, such that positive scores indicate less perceived crime and better neighbourhood quality while negative scores indicate more

perceived crime and poorer quality. The scales were derived following an exploratory factor analysis of 14 questions regarding neighbourhood (Supplementary Table 1).

Dependent variables

Height was measured to the last complete millimetre using a portable stadiometer; weight was measured to the nearest kilogram using a Tanita SC-240 Body Composition Analyzer (Tanita, Tokyo, Japan); body mass index (BMI) was derived as weight(kg)/height(m)^2. The Tanita SC-240 Body Composition Analyzer also measured leg-to-leg bioelectrical impedance from which fat free mass and fat mass were estimated. Fat mass percentage was calculated as fat mass (kg)/weight (kg)*100.

Participants wore a hip-mounted ActiGraph GT3X+ accelerometer during waking hours over a consecutive period of 7 days (ActiGraph LLC, Florida, USA). These accelerometers provided daily measures of steps, counts and time spent in moderate and vigorous PA (MVPA) using established cut-offs. Daily time spent in MVPA both overall and in ≥10 minute bouts in accordance with UK recommendations for PA (32) were assessed. The cut-point for moderate PA was defined as ≥1952 counts per minute (33). We excluded any days of recording where the amount of registered time accumulated was below 540 minutes (34). Non-wear periods were defined as a minimum length of 60 minutes, allowing for a 2-minute spike tolerance. Participants with at least one day of recording were retained in analyses. We fitted a multilevel linear model for each outcome to allow for repeated measurements of daily PA, by fitting participant as a random effect and adjusting for day of the week, day order of recording and month as fixed effects. Raw level one residuals were obtained from the model and a within person average value of each outcome variable was obtained by

averaging these raw residuals. The average of these raw residuals for each participant was added to the sample mean for that particular PA variable to derive an unbiased average level of each PA variable for each person.

Statistical analysis

All analyses were carried out using STATA/SE software (Stata/SE 14 for Windows; StataCorp LP, College Station, TX, USA). Outcome variables were inspected for normality and BMI was log transformed due to its skewed distribution. Multilevel linear regression models were fitted, mutually adjusted for housing sector and participant characteristics (sex, age group, ethnic group, and limiting longstanding illness) as fixed effects, with a random effect to allow for household clustering. Residuals did not show departure from linearity, suggesting that the model assumptions were appropriate. Absolute differences or percentage differences for log transformed outcomes (i.e. BMI) are presented by sex, age group, ethnic group, limiting longstanding illness and housing sector. Sensitivity analyses examined whether associations remained when the sample was restricted to 931 participants (84%) with at least four days of 540 or more minutes per day of recording.

To assess differences in PA by day of the week as opposed to overall levels of PA we took the following approach. Daily PA data were examined using multilevel models with random effects to allow for multiple days of recording within person and household clustering. An interaction between housing sector and day of the week was fitted and models were adjusted for sex, age group, ethnic group, limiting longstanding illness, day order of recording and month of measurement as fixed effects.

The associations between neighbourhood perception scales and adiposity and PA outcomes were examined. Each of the neighbourhood quality and crime scores were included in the models as quintiles, to examine the differences in outcomes between the top and bottom quintile. Finally, the effect of adjustment for neighbourhood perception on differences in adiposity and PA between housing sectors was examined. If associations between outcomes and neighbourhood perceptions appeared linear, models examining housing sector differences were additionally adjusted for neighbourhood perceptions as a continuous variable.

Patient and Public Involvement

The ENABLE London study was developed in partnership with a network of both local and regional stakeholders identified through our collaborator links to agencies, involved with the design, planning and management of large-scale accommodation developments. Locally these included local authorities (particularly Newham) and a number of housing associations, in particular Triathlon Homes, a partner organisation of housing associations, which manages social and intermediate homes in East Village. Participants have been involved in the study from an early stage to ensure assessments and participation remain relevant and enjoyable, to ensure the continued significance and potential generalisability of the work.

Results

Of 1819 households who agreed to be contacted by the study team in order to receive further information about the ENABLE London study, 1278 adults from 1006 households (55%) participated in the study and completed a questionnaire. Participation rates for those

seeking market-rent and intermediate housing were 58% and 57% respectively and were slightly lower in the social group (52%). Complete data on adiposity were available for 1240 participants (97%); of these a sub-set of 1107 participants (89%) met the inclusion criteria for analyses of objectively measured PA. Participant characteristics (age, sex) and levels of adiposity were similar among those who did and did not provide PA data; however, participants from black and Asian ethnic groups were less likely to provide PA data. Supplementary Table 2 shows participants characteristics at baseline for the 1240 adults with measurements of adiposity at baseline. Those seeking social housing were more likely to be female, of older age, of non-white ethnicity, to have limiting longstanding illness, and be in routine / manual occupations or economically inactive compared to those seeking intermediate or market-rent housing.

Adjusted mean levels of adiposity and PA outcomes by housing sector and participant characteristics are shown in Supplementary Table 3. Table 1 shows housing sector and other participant characteristics associations with BMI and fat mass %, and objectively measured PA (steps, time spent in MVPA, time spent in MVPA in ≥10 minute bouts). Participants seeking social housing had markedly higher levels of BMI and fat mass % and markedly lower levels of steps, MVPA and MVPA in ≥10 minute bouts compared with those seeking intermediate housing, though there were no differences between those seeking market-rent and intermediate accommodation.

Fat mass % was higher in females than males though there was no difference in BMI (Table 1). BMI and fat mass % were higher among all older age groups compared with 16-24 year olds. Participants of black ethnicity had higher levels of BMI and fat mass % compared with

whites; there were no differences in BMI and fat mass % between Asian or other/mixed ethnic groups and whites. Those with a limiting longstanding illness had higher levels of both BMI and fat mass %. All PA measures were lower among females. Steps and MVPA were slightly higher in 25-34 year olds and steps were also higher among 35-49 year olds compared with 16-24 year olds; however, there were no age group differences for MVPA in ≥10 minute bouts. Participants of black and Asian ethnicities had lower levels of steps, MVPA and MVPA in ≥10 minute bouts compared to whites. Participants who reported having a limiting longstanding illness had lower levels of steps and MVPA, but not MVPA in ≥10 minute bouts. Educational attainment level was not associated with any of the outcomes once housing sector had been adjusted for and adjustment for educational attainment did not materially alter housing sector differences in adiposity or PA outcomes (data available from authors).

Sensitivity analyses for PA outcomes were carried out in 931 participants who wore an ActiGraph for at least four days with at least 540 minutes of recording per day (Supplementary Table 4). There were no differences between market-rent and intermediate groups (consistent with the main analysis presented in Table 1). Differences between social and intermediate groups were broadly similar with the results presented in Table 1 for the main analysis.

Differences in PA variables between housing groups were examined by day of the week to explore whether differences between groups were consistent across the week (Figure 1A-D). Levels of PA (steps (panel A), MVPA (panel B) and MVPA in ≥10 minute bouts (panel C)) were generally consistent across weekdays (Monday – Friday) among all groups. In the

intermediate group, steps were higher on Saturdays and lower on Sundays; MVPA and MVPA in ≥10 minute bouts were lower on Sundays but there was no difference on Saturdays compared to weekday activity. In the market-rent group, steps, MVPA and MVPA in ≥10 minute bouts were higher on Saturdays and similar to weekdays on Sundays. In the social group, steps, MVPA and MVPA in ≥10 minute bouts were on average lower on Saturdays and lower still on Sundays. Registered time (panel D) was lowest on average in the social group during weekdays, decreasing on Saturdays and Sundays. The intermediate and market-rent groups had higher levels of registered time during weekdays compared with the social group which decreased on average on Saturdays and Sundays (despite recording more steps and minutes in MVPA suggesting a higher intensity of activity). Mean levels of steps, MVPA, and MVPA in ≥10 minute bouts on weekdays and differences on Saturday and Sunday compared to weekdays are shown by housing sector in Supplementary Table 5. The marked differences in activity between weekdays and weekend days in the social group are not explained by differences in registered time (data available from authors).

Associations between perceived neighbourhood quality and crime scales and adiposity and PA outcomes are shown in Table 2, adjusted for the participant characteristics shown in Table 1. Participants with the most positive perceptions of neighbourhood quality (highest quintile) had lower BMI, higher steps and recorded longer durations of MVPA compared with those who had the most negative perceptions of neighbourhood quality (lowest quintile). There were no significant associations between perceptions of neighbourhood crime and adiposity or PA.

The effect of adjustment for perceived neighbourhood quality on differences in adiposity and PA between housing sector groups is presented in Table 3. All associations between perceived neighbourhood quality and crime and outcome variables were approximately linear and were therefore fitted as continuous variables in the model. In addition, associations between perceived neighbourhood quality and crime and outcome variables were similar across the three housing groups (all $p>0.05$). Adjustment for perceptions of neighbourhood quality reduced differences in BMI, fat mass %, steps, MVPA and MVPA in ≥10 minute bouts between the social and intermediate groups by 10%, 6%, 10%, 10% and 7% respectively. Differences between market-rent and intermediate groups in adiposity and PA variables were not statistically significant before or after adjustment. A larger proportion of the social-intermediate group differences in steps, MVPA and MVPA in ≥10 minute bouts on weekends was explained by adjustment for perceptions of neighbourhood quality (10%, 16% and 16% respectively) compared to the differences in steps, MVPA and MVPA in ≥10 minute bouts on weekdays which were reduced by 10%, 8% and 3% respectively (data not shown).

Discussion

The results of this study showed that participants seeking social housing in East Village had lower levels of PA and higher levels of BMI and fat mass % compared with those seeking intermediate and market-rent housing, even when adjusted for demographic factors. In the social housing group, levels of PA were particularly low on weekends compared with weekdays possibly reflecting higher occupational PA and lower leisure time PA; weekday-weekend differences in PA were less marked among those seeking intermediate and market-rent housing. However, the lower registered time at weekends but higher MVPA

and steps suggests more intense activity at weekends in the intermediate and market-rent housing groups. These findings may inform targeted interventions to increase PA and reduce adiposity in different socioeconomic groups.

Positive associations between perceived neighbourhood quality and PA, BMI and fat mass % were also shown. Adjustment for differences in perceived neighbourhood quality reduced differences in PA and BMI by approximately 10% between social and intermediate housing groups; equivalent to a reduction of 111 for daily steps, 0.5 minutes for MVPA and 0.5kg/m^2 for BMI. However, a larger proportion of the difference in PA was apparent at weekends; equivalent to a reduction of 222 for daily steps and 2.2 minutes for MVPA.

Relation to previous studies

Studies have shown that lower socioeconomic status is associated with lower levels of PA (35;36), and that those from more socially deprived backgrounds have the most barriers to being physically active (7). Previous research examining the role of housing tenure is limited. Findings from this study showed marked differences in PA and adiposity between those seeking social, intermediate and market-rent housing. In particular, lower PA and higher adiposity in participants seeking social housing, a group which comprises a high proportion of people from more socioeconomically disadvantaged backgrounds (28). The higher levels of BMI and fat mass % in those seeking social housing compared with those seeking intermediate or market-rent housing is consistent with systematic reviews which have found an association between lower socioeconomic status and higher levels of adiposity, particularly in higher income countries and among women (37). While socioeconomic status is a strong determinant of housing status, to our knowledge this is the first study to

explicitly examine housing sector differences in objective PA and markers of adiposity levels (i.e. BMI and fat mass %). However, it is important to consider more broadly what these aspirational housing sector differences might represent. Related studies have shown that those in social housing are less likely to use active travel compared with owner occupiers (18), and that those in social housing and home owners with a mortgage are more likely to be obese and have higher levels of illness and disability compared to outright home owners, even after adjustment for other socioeconomic status markers (38). These latter findings suggest that the effect of home ownership may be more complex and cannot be simply explained by socioeconomic status. Neighbourhood quality may offer a potential partial explanation for these findings (39). In the present study perceptions of better neighbourhood quality were associated with PA whereas perceptions of crime were not. In contrast, a large UK-based study found that perceptions of feeling safe in the neighbourhood had the largest effect on levels of PA compared with perceptions of leisure facilities, sense of belonging or access to public transport or amenities (40). Another study in the US found that low perceived safety from crime was associated with lower levels of MVPA (41). However, a recent review concluded that higher quality evidence is needed, including prospective studies and natural experiments in areas of wide crime variability, in order to further understand the effect of crime on physical and mental health (27). Moreover, previous work has suggested that objective and perceived measures of the built environment correlate differently with physical activity levels, suggesting that these measures are assessing different dimensions of the built environment which relate differently to health behaviour (42).

Our findings showed that PA levels were particularly low on the weekend among those seeking social housing, which is consistent with findings from a systematic review which found that leisure-time PA (which may be more likely to occur on weekends) was lower amongst those from lower socioeconomic groups (8). This suggests that low-cost strategies to increase weekend PA may be particularly beneficial to more disadvantaged households. A free community-based program in Bogata Colombia, temporarily closed streets on Sundays to encourage PA amongst more disadvantaged local residents (43). A similar program has been trialled in the United States (44), however the effectiveness, longevity and generalisability of these programs to other socioeconomically deprived areas is yet to be established.

Strengths and limitations

Strengths of this study include the representation of three different aspirational housing groups which provides a wide range of socioeconomic backgrounds. Of those seeking social housing, two-thirds (67%) were currently living in social housing accommodation provided by the local authority or housing association; the remainder were largely currently living in privately rented accommodation with many on social housing waiting lists. Of those seeking intermediate or market-rent accommodation, almost two-thirds were living in privately rented accommodation (both 64%); the remainder were largely living with relatives or friends. The study sample is large with good representation from a 'hard to reach' group of social housing participants. Participation rates were high given the target group, with between 50-60% of those who initially agreed to be contacted taking part in the study. The ActiGraph GT3X+ accelerometer provided validated objective measures of PA (45) and the use of bioelectrical impedance to provide more direct measurements of adiposity including

fat mass %, which may provide a more valid marker of adiposity than BMI, particularly in a multi-ethnic population (46;47). Reassuringly the patterns of PA by sex, ethnic group and health status were consistent with those published previously (48-50). A limitation of the study is the lower number of participants in the market-rent sector compared with the other groups. This was due to restrictions imposed on the study team on the extent and duration of access to potential applicants seeking market-rent accommodation. While the study is longitudinal, these analyses are cross-sectional limiting the degree to which causal inferences can be made. Moreover, there is the possibility of selection amongst study participants, where those who are more active seek to move to East Village, may be more likely to participate in the study and may perceive their environment differently, which may limit the generalisability of the findings to neighbourhoods outside of East London.

Conclusions and future work

The findings presented in this paper suggest that perceived neighbourhood quality is associated with meaningful differences in PA and markers of adiposity. Differences in steps (680 steps) and BMI (3.6kg/m²) between the lowest and highest quintiles of perceived neighbourhood quality should be considered in the context of an average 10,000 steps per day, where a 5% increase (500 steps) would be a worthwhile population level increase and a 5kg/m² increase in BMI is associated with a 31% increase in all-cause mortality (51). Hence, improvements in neighbourhood quality could be associated with health benefits of public health importance. There were also substantial differences in PA, BMI and fat mass % between the three housing groups studied. In particular the very low levels of PA in the social housing group during the weekend could provide a target for intervention to increase levels of PA; again these differences should be considered in relation to 500 steps per day,

which can be considered as an increase of population importance. Perceptions of neighbourhood quality reduced differences in PA and adiposity between housing sector groups, and the possibility of measuring more objective markers of neighbourhood quality within this study has the potential to explain more (42). The future follow-up of the ENABLE London cohort will allow us to examine whether moving to 'East Village', a neighbourhood designed for healthy active living, will have a positive impact on PA and/or adiposity levels. A major aim of the study is to identify features of the local built environment that increase levels of PA which could potentially help to reduce socioeconomic inequalities in health. It will be of particular interest to determine whether an increase in PA is more apparent in the social housing group whose neighbourhood characteristics should improve. Furthermore, we will be in a position to examine whether any potential effects of the built environment on PA are modified by housing sector type.

Ethical approval

Full ethical approval was obtained from the relevant Multi-Centre Research Ethics Committee (REC Reference 12/LO/1031). All participants provided written informed consent.

Data sharing statement

Further details of the ENABLE London study are available from the study website (http://www.enable.sgul.ac.uk/). We welcome proposals for collaborative projects. For general data sharing inquiries, contact Professor Owen (cowen@sgul.ac.uk).

Competing interests

We declare that we have no competing interests.

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Authorship statement

CGO, ARR, AE, ARC, DL, SC, BG-C, DGC and PHW designed the study and raised funding. BR, ARR, CC, DP and CGO collected data for the study; BR, ARR and CGO enrolled participants. CMN, BR, ESL, ARR, CC, DP and CGO undertook data management. CMN, ESL analysed the data; CMN wrote the first draft of the report. ARR, BR, ESL, AS, DP, ARC, ASP, AE, BG-C, CC, DL, SC, PHW, DGC and CGO critically appraised the manuscript and approved the final draft. CGO is responsible for data integrity.

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Table 1: Associations between adiposity and physical activity outcomes and patient characteristics

		Difference or % difference* in adiposity/physical activity (95% CI), p-value														
	n	BMI (kg/m^2)*			Fat mass %			Daily steps†			Daily minutes spent in MVPA†			Daily minutes spent in MVPA in ≥10 minute bouts†		
Sex																
Male (Ref)	522			-			-			-			-			-
Female	718	-1.2	(-3.2, 0.9)	0.26	11.1	(10.3, 12.0)	<0.0001	-570	(-946, -194)	0.003	-9.3	(-12.2, -6.4)	<0.0001	-4.1	(-6.1, -2.0)	<0.001
Age group																
Age 16-24 (Ref)	269			-			-			-			-			-
Age 25-34	531	6.3	(3.5, 9.1)	<0.0001	3.2	(2.1, 4.3)	<0.0001	502	(11, 992)	0.04	4.0	(0.2, 7.9)	0.04	1.0	(-1.9, 3.8)	0.51
Age 35-49	358	13.4	(10.2, 16.6)	<0.0001	6.4	(5.2, 7.6)	<0.0001	699	(173, 1224)	0.01	3.9	(-0.2, 8.0)	0.07	-1.1	(-4.0, 1.8)	0.46
Age 50+	82	17.6	(12.6, 22.9)	<0.0001	9.2	(7.3, 11.0)	<0.0001	-9	(-832, 813)	0.98	-6.0	(-12.4, 0.5)	0.07	-2.0	(-6.8, 2.7)	0.40
Ethnic group																
White (Ref)	595			-			-			-			-			-
Black	314	6.2	(3.3, 9.3)	<0.0001	3.6	(2.4, 4.8)	<0.0001	-1116	(-1657, -575)	<0.0001	-7.4	(-11.7, -3.2)	<0.001	-6.6	(-9.8, -3.4)	<0.0001
Asian	210	-0.3	(-3.1, 2.7)	0.85	0.02	(-1.2, 1.3)	0.97	-1409	(-1972, -845)	<0.0001	-11.5	(-15.9, -7.0)	<0.0001	-8.1	(-11.4, -4.8)	<0.0001
Other/Mixed	121	1.3	(-2.3, 5.0)	0.48	1.0	(-0.5, 2.5)	0.18	-430	(-1100, 239)	0.21	-4.6	(-9.8, 0.7)	0.09	-4.0	(-7.9, -0.04)	0.05
Limiting illness																
No (Ref)	1087			-			-			-			-			-
Yes	153	4.3	(1.1, 7.5)	0.01	1.6	(0.3, 2.9)	0.01	-1081	(-1666, -496)	<0.001	-5.7	(-10.3, -1.1)	0.01	-2.8	(-6.1, 0.5)	0.10
Housing sector																
Social	512	5.0	(2.2, 7.8)	<0.001	2.7	(1.5, 3.8)	<0.0001	-1125	(-1629, -620)	<0.0001	-7.5	(-11.5, -3.6)	<0.001	-6.5	(-9.5, -3.5)	<0.0001
Intermediate (Ref)	503			-			-			-			-			-
Market-rent	225	-0.8	(-3.6, 2.0)	0.57	-0.2	(-1.4, 1.0)	0.70	-104	(-633, 424)	0.70	2.3	(-1.9, 6.4)	0.29	2.8	(-0.3, 6.0)	0.08

* Percentage differences are presented for BMI, which was log-transformed for analysis

All differences and % differences are mutually adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level

† Missing data for 133 participants

MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

Table 2: Associations between adiposity and physical activity outcomes and neighbourhood perceptions scales

	Difference or % difference* in outcome between the highest and lowest quintiles for each neighbourhood scale (95% CI), p-value					
	Perceptions of NH quality			Perceptions of NH crime		
Adiposity (N = 1240)						
Body mass index (kg/m^2)*	-3.6	(-6.5, -0.6)	0.02	-2.1	(-5.4, 1.3)	0.21
Fat mass %	-1.2	(-2.5, 0.06)	0.06	-0.8	(-2.2, 0.7)	0.30
Physical activity (N = 1107)						
Daily steps	677	(108, 1247)	0.02	-63	(-713, 587)	0.85
Daily MVPA (minutes)	4.5	(0.02, 9.0)	0.05	1.1	(-4.0, 6.2)	0.68
Daily MVPA in ≥10 minute bouts (minutes)	2.7	(-0.6, 6.0)	0.11	2.4	(-1.4, 6.1)	0.22

* Percentage differences are presented for BMI, which was log-transformed for analysis

All differences and % differences are adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level.

Abbreviations: NH, neighbourhood

MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

Table 3: Adiposity and physical activity differences between housing sectors: adjustment for perceptions of neighbourhood quality

	Housing sector group	Difference or % difference* compared to intermediate housing group (95% confidence interval), p-value					
		Model 1			Model 2 (Additionally adjusted for neighbourhood quality scale)		
Adiposity (N = 1240)							
Body mass index (kg/m^2)*	Social	5.0	(2.2, 7.8)	<0.001	4.5	(1.7, 7.3)	0.002
	Intermediate	Reference group					
	Market rent	-0.8	(-3.6, 2.0)	0.57	-0.9	(-3.6, 2.0)	0.55
Fat mass %	Social	2.7	(1.5, 3.8)	<0.0001	2.5	(1.4, 3.6)	<0.0001
	Intermediate	Reference group					
	Market rent	-0.2	(-1.4, 1.0)	0.70	-0.2	(-1.4, 0.9)	0.68
Physical activity (N = 1107)							
Daily steps	Social	-1125	(-1629, -620)	<0.0001	-1016	(-1531, -501)	<0.001
	Intermediate	Reference group					
	Market rent	-104	(-633, 424)	0.70	-96	(-624, 431)	0.72
Daily MVPA (minutes)	Social	-7.5	(-11.5, -3.6)	<0.001	-6.8	(-10.8, -2.7)	0.001
	Intermediate	Reference group					
	Market rent	2.3	(-1.9, 6.4)	0.29	2.3	(-1.8, 6.5)	0.27
Daily MVPA in ≥10 minute bouts (minutes)	Social	-6.5	(-9.5, -3.5)	<0.0001	-6.0	(-9.1, -3.0)	<0.001
	Intermediate	Reference group					
	Market rent	2.8	(-0.3, 6.0)	0.08	2.8	(-0.3, 6.0)	0.08

* Percentage differences are presented for BMI, which was log-transformed for analysis

Model 1: Adjusted for sex, age group, ethnic group, limiting longstanding illness and clustering at household level (random effect)

Model 2: Adjusted as Model 1 plus neighbourhood quality scale (added as a continuous variable)

MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

Figure 1: Daily physical activity by day of the week and housing sector group: N = 6206 days from 1107 participants

Means and 95% confidence intervals are adjusted for sex, age group, ethnic group, limiting longstanding illness, month of recording, day order of recording, day of week, housing sector, an interaction between housing sector and day of week and random effects to allow for multiple days of measurement and clustering of participants within households

1

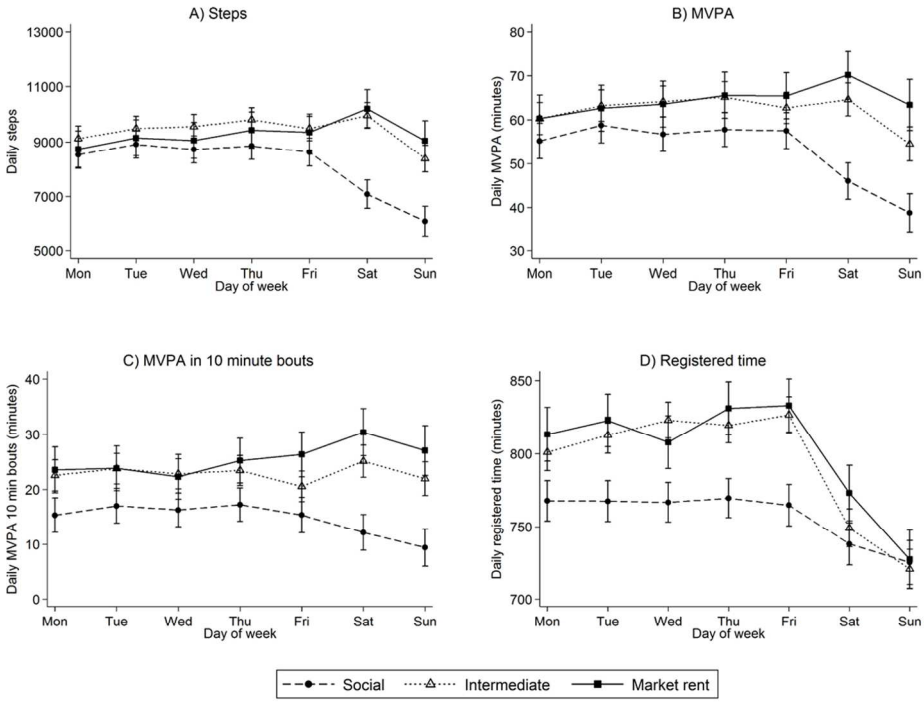

Figure 1: Daily physical activity by day of the week and housing sector group: N = 6206 days from 1107 participants

119x90mm (300 x 300 DPI)

Supplementary Table 1: Questionnaire items included in the factor analysis on perceptions of the neighbourhood

Perceptions of neighbourhood crime items
There is a lot of crime in my neighbourhood.
The level of crime in my neighbourhood makes it unsafe to walk on the streets at night.
There are threatening groups of young people in my neighbourhood.
The level of crime in my neighbourhood makes it unsafe to walk on the streets during the day.
Vandalism, graffiti or deliberate damage to property is a problem in my local area.
Perceptions of neighbourhood quality items
I enjoy walking in my neighbourhood.
This area is a place I enjoy living in.
My neighbourhood is attractive to look at (e.g. there are attractive buildings, green space. Landscaping views).
This area has good leisure things for people like myself, leisure centres or community centres for example.
You often see people out on walks or riding their bicycles in my neighbourhood.
This area has good local transport.
Additional items included in the factor analysis with factor loadings below 0.4 and were therefore not included in the solution
My neighbourhood is generally free from litter.
There is too much traffic in my neighbourhood.
Our neighbourhood streets have good lighting at night.

Participants were asked to select a response from the following for all questionnaire items stated in the table: Strongly agree, Agree, Neither agree nor disagree, Disagree, Strongly disagree

Supplementary Table 2: Participant characteristics for 1240 adults with measurements of adiposity at baseline

	Housing sector								
	Social		Intermediate		Market rent		Total		
	(n = 512)		(n = 503)		(n = 225)		(N = 1240)		p (χ^2)
Sex									
Male	137	(26.8%)	259	(51.5%)	126	(56.0%)	522	(42.1%)	
Female	375	(73.2%)	244	(48.5%)	99	(44.0%)	718	(57.9%)	<0.0001
Age group									
16-24	107	(20.9%)	92	(18.3%)	70	(31.1%)	269	(21.7%)	
25-34	129	(25.2%)	291	(57.9%)	111	(49.3%)	531	(42.8%)	
35-49	233	(45.5%)	102	(20.3%)	23	(10.2%)	358	(28.9%)	
50+	43	(8.4%)	18	(3.6%)	21	(9.3%)	82	(6.6%)	<0.0001
Ethnic group									
White	96	(18.8%)	342	(68.0%)	157	(69.8%)	595	(48.0%)	
Black	245	(47.9%)	53	(10.5%)	16	(7.1%)	314	(25.3%)	
Asian	107	(20.9%)	75	(14.9%)	28	(12.4%)	210	(16.9%)	
Mixed/Other	64	(12.5%)	33	(6.6%)	24	(10.7%)	121	(9.8%)	<0.0001
NS-SEC*									
Higher Managerial / Professional	60	(11.9%)	357	(71.4%)	150	(66.7%)	567	(46.1%)	
Intermediate Occupations	62	(12.3%)	77	(15.4%)	38	(16.9%)	177	(14.4%)	
Routine / Manual	125	(24.8%)	34	(6.8%)	10	(4.4%)	169	(13.7%)	
Economically inactive	258	(51.1%)	32	(6.4%)	27	(12.0%)	317	(25.8%)	<0.0001
Limiting illness									
Yes	102	(19.9%)	40	(8.0%)	11	(4.9%)	153	(12.3%)	
No	410	(80.1%)	463	(92.0%)	214	(95.1%)	1087	(87.7%)	<0.0001

p (χ^2): p-value for Chi-squared test

* 10 responses missing for NS-SEC group

Supplementary Table 3: Mean levels of adiposity and physical activity by patient characteristics

		Mean/Geometric mean* levels adiposity and physical activity (95% confidence intervals)				
	n	BMI (kg/m^2)*	Fat mass %	Daily steps†	Daily minutes of MVPA†	Daily minutes of MVPA in ≥10 minute bouts†
Sex						
Male	522	25.4 (25.0, 25.8)	20.4 (19.7, 21.0)	9279 (8991, 9568)	64.8 (62.6, 67.1)	22.8 (21.1, 24.4)
Female	718	25.1 (24.8, 25.5)	31.5 (30.9, 32.0)	8709 (8464, 8954)	55.6 (53.6, 57.5)	18.7 (17.3, 20.1)
Age group						
Age 16-24	269	23.5 (23.0, 24.0)	23.0 (22.1, 23.9)	8534 (8136, 8932)	57.0 (53.9, 60.2)	20.5 (18.2, 22.8)
Age 25-34	531	25.0 (24.6, 25.3)	26.2 (25.5, 26.8)	9035 (8744, 9326)	61.1 (58.8, 63.3)	21.4 (19.7, 23.1)
Age 35-49	358	26.6 (26.1, 27.1)	29.3 (28.5, 30.1)	9232 (8879, 9585)	60.9 (58.1, 63.6)	19.4 (17.3, 21.4)
Age 50+	82	27.6 (26.6, 28.7)	32.2 (30.5, 33.8)	8525 (7800, 9249)	51.1 (45.4, 56.7)	18.4 (14.2, 22.7)
Ethnic group						
White	595	24.9 (24.5, 25.2)	25.8 (25.1, 26.4)	9491 (9203, 9779)	63.6 (61.3, 65.8)	23.7 (22.0, 25.4)
Black	314	26.4 (25.8, 27.0)	29.4 (28.5, 30.3)	8375 (7961, 8789)	56.2 (52.9, 59.4)	17.1 (14.7, 19.6)
Asian	210	24.8 (24.2, 25.4)	25.8 (24.8, 26.8)	8082 (7608, 8556)	52.1 (48.4, 55.8)	15.6 (12.8, 18.4)
Other/Mixed	121	25.2 (24.4, 26.0)	26.8 (25.5, 28.1)	9060 (8465, 9656)	59.0 (54.3, 63.7)	19.8 (16.3, 23.3)
Limiting illness						
No	1087	25.1 (24.9, 25.4)	26.6 (26.1, 27.0)	9077 (8877, 9277)	60.1 (58.6, 61.7)	20.8 (19.6, 21.9)
Yes	153	26.2 (25.5, 27.0)	28.2 (27.0, 29.4)	7996 (7447, 8545)	54.4 (50.1, 58.7)	18.0 (14.8, 21.1)
Housing sector						
Social	512	26.0 (25.6, 26.5)	28.4 (27.6, 29.1)	8298 (7953, 8642)	54.6 (51.8, 57.3)	16.0 (14.0, 18.1)
Intermediate	503	24.8 (24.4, 25.2)	25.7 (25.0, 26.4)	9422 (9110, 9735)	62.1 (59.6, 64.5)	22.5 (20.6, 24.4)
Market-rent	225	24.6 (24.0, 25.2)	25.5 (24.5, 26.5)	9318 (8863, 9773)	64.3 (60.8, 67.9)	25.3 (22.6, 28.1)

* Geometric means are presented for BMI

All means/geometric means are adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level.

† Data missing for 133 participants for average daily steps, MVPA and MVPA in bouts

Supplementary Table 4: Associations between participant characteristics and physical activity variables in participants with at least 4 days of recording of physical activity data

		Difference or % difference* in physical activity variable (95% confidence interval), p-value								
	n	Daily steps			Daily minutes spent in MVPA			Daily minutes spent in MVPA in ≥10 minute bouts		
Sex										
Male (Ref)	402		-			-			-	
Female	529	-559	(-947, -172)	0.005	-9.7	(-12.7, -6.7)	<0.0001	-4.7	(-6.8, -2.5)	<0.0001
Age group										
Age 16-24 (Ref)	180		-			-			-	
Age 25-34	412	410	(-116, 936)	0.13	3.0	(-1.2, 7.2)	0.16	-0.3	(-3.3, 2.8)	0.87
Age 35-49	276	520	(-45, 1086)	0.07	2.5	(-2.0, 6.9)	0.27	-2.5	(-5.7, 0.7)	0.12
Age 50+	63	-25	(-889, 838)	0.95	-7.9	(-14.8, -1.1)	0.02	-3.2	(-8.2, 1.8)	0.20
Ethnic group										
White (Ref)	482		-			-			-	
Black	214	-1213	(-1789, -638)	<0.0001	-7.1	(-11.7, -2.5)	0.002	-6.5	(-9.9, -3.1)	<0.001
Asian	142	-1128	(-1719, -538)	<0.001	-10.3	(-15.0, -5.6)	<0.0001	-7.8	(-11.3, -4.3)	<0.0001
Other/Mixed	93	-582	(-1273, 110)	0.10	-4.7	(-10.2, 0.8)	0.09	-4.2	(-8.2, -0.2)	0.04
Limiting illness										
No (Ref)	834		-			-			-	
Yes	97	-976	(-1612, -341)	0.003	-4.6	(-9.6, 0.4)	0.07	-2.0	(-5.6, 1.6)	0.28
Housing sector										
Social	332	-978	(-1515, -440)	<0.001	-6.9	(-11.2, -2.6)	0.002	-7.2	(-10.4, -4.0)	<0.0001
Intermediate (Ref)	410		-			-			-	
Market-rent	189	-359	(-889, 171)	0.185	0.2	(-4.0, 4.3)	0.91	0.9	(-2.2, 4.1)	0.56

All differences are mutually adjusted for sex, age group, ethnic group, limiting longstanding illness, housing sector and a random effect to allow for clustering at household level.
MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

Supplementary Table 5: Physical activity differences between weekday (Monday-Friday) and weekend (Saturday, Sunday) activity by housing sector.

Physical activity variable (N = 1107)	Housing sector group	Mean (95% CI) weekday (Mon-Fri) activity		Difference in PA outcome compared to weekdays (95% confidence interval), p-value					
				Saturday - weekday			Sunday - weekday		
Daily steps	Social	8733	(8364, 9103)	-1643	(-2078, -1207)	<0.0001	-2629	(-3093, -2164)	<0.0001
	Intermediate	9497	(9178, 9817)	460	(59, 862)	0.02	-1104	(-1528, -680)	<0.0001
	Market-rent	9146	(8673, 9619)	1055	(467, 1642)	<0.001	-102	(-734, 531)	0.75
MVPA (minutes)	Social	57.2	(54.3, 60.1)	-11.2	(-14.7, -7.7)	<0.0001	-18.4	(-22.1, -14.7)	<0.0001
	Intermediate	63.1	(60.6, 65.7)	1.5	(-1.8, 4.7)	0.37	-8.5	(-11.9, -5.1)	<0.0001
	Market-rent	63.5	(59.8, 67.3)	6.6	(1.9, 11.3)	0.01	-0.1	(-5.2, 5.0)	0.97
MVPA in ≥10 minute bouts (minutes)	Social	16.3	(14.0, 18.5)	-4.1	(-6.9, -1.3)	0.004	-6.8	(-9.8, -3.9)	<0.0001
	Intermediate	22.6	(20.7, 24.6)	2.5	(-0.06, 5.1)	0.06	-0.7	(-3.4, 2.0)	0.62
	Market-rent	24.2	(21.3, 27.1)	6.1	(2.4, 9.9)	0.001	2.8	(-1.2, 6.9)	0.17

Means and differences (95% confidence intervals) are adjusted for sex, age group, ethnic group, limiting longstanding illness, month of recording, day of the week, housing sector, an interaction between housing sector and day of week, and random effects to allow for multiple days of measurement and clustering of participants within household.

MVPA and MVPA in ≥10 minute bouts are an average daily estimate, obtained from averaging a participant's weekly total.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page / line number at first call out
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2 / 7
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2 / 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5 / 9
Objectives	3	State specific objectives, including any prespecified hypotheses	6 / 7
Methods			
Study design	4	Present key elements of study design early in the paper	6 / 16
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7 / 4
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6 / 18
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8 / 5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*8 / 5*
Bias	9	Describe any efforts to address potential sources of bias	10 / 14
Study size	10	Explain how the study size was arrived at	11 / 22
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8 / 6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10 / 8
		(*b*) Describe any methods used to examine subgroups and interactions	10 / 12
		(*c*) Explain how missing data were addressed	Table 1
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases	10 / 8

		and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	10 / 14
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11 / 22
		(b) Give reasons for non-participation at each stage	19 / 8
		(c) Consider use of a flow diagram	N / A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	12 / 7
		(b) Indicate number of participants with missing data for each variable of interest	Table 1
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	*12 / 2*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	12 /13
		(*b*) Report category boundaries when continuous variables were categorized	12 /13
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N / A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	13 / 14
Discussion			
Key results	18	Summarise key results with reference to study objectives	15 / 18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	19 / 3
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	19 / 14
Generalisability	21	Discuss the generalisability (external validity) of the study results	19 / 19
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	21 / 16

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.