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**Title:** Loneliness, Social Isolation and Objectively-Measured Physical Activity in Rurally-Living Older Adults

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**Conflict of interest statement:**

None of the authors have a conflict of interest relating to this study.

Loneliness, Social Isolation and Objectively-Measured Physical Activity in Rural-living Older Adults

## Abstract

This cross-sectional, observational study examined whether objectively-measured physical activity (PA) and specific activities are associated with loneliness and social isolation (SI) in rural-living older adults.

One-hundred-and-twelve participants (mean age=72.8 [SD=6.6], 51.8% female) from 23 villages in Wiltshire, England, completed questionnaires, seven-day accelerometry and activity diaries. Regression analysis was used to: 1) test associations between objectively-measured light (LPA), moderate-to-vigorous (MVPA) and total PA (TPA), loneliness and SI from family, neighbours or friends; 2) explore these associations using specific activities.

Daily mean LPA, MVPA and TPA were not associated with loneliness or SI. Volunteering, accompanying others and sports/exercise were associated with lower SI from neighbours (OR=0.23, 95% CI:0.06-0.91), family (OR=0.39, 95% CI:0.22-0.68) and friends (OR=0.56, 95% CI:0.33-0.97), respectively.

There were no associations between loneliness, SI and objectively-measured PA. The contribution of PA to loneliness and SI need to be further investigated with larger and diverse samples of rural-living older adults.

## Key words

Ageing, health, social well-being, accelerometry, volunteering

## Introduction

Loneliness and social isolation (SI), seen as distinct concepts, have been associated with increased risk of morbidity and mortality (Elovainio et al., 2017; Holt-Lunstad, Smith, Baker, Harris, & Stephenson, 2015; Shankar, McMunn, Demakakos, Hamer, & Steptoe, 2017; Valtorta, Kanaan, Gilbody, Ronzi, & Hanratty, 2016). In older age in particular, loneliness and SI have been observationally associated with lower levels of physical activity (PA) (Hawkey, Thisted, & Cacioppo, 2009; Netz, Goldsmith, Shimony, Arnon, & Zeev, 2013; Shankar, McMunn, Banks, & Steptoe, 2011). This has prompted the development of PA interventions targeting older populations with the aim of reducing loneliness and/or SI (Pels & Kleinert, 2016; Shvedko, Thompson, Greig, & Whittaker, 2018b).

### **Loneliness and low physical activity**

Evidence has accumulated showing an association between loneliness and self-reported PA (Pels & Kleinert, 2016). In 14 studies with older adults, included in a systematic review, three of the six cross-sectional studies, all three longitudinal studies, and all five intervention studies in older populations supported the association between loneliness, defined as a subjective feeling of a lack of social contact, and low self-reported PA (Pels & Kleinert, 2016). A more recent prospective study, following 466,901 participants between age 40 and 69 over six years, also found an association between loneliness and self-reported moderate PA ( $r=-0.02$ ) and vigorous PA ( $r=-0.02$ ) (Elovainio et al., 2017). Hawkey and Cacioppo (2010) have proposed that low PA levels are a mechanism through which loneliness leads to long-term health deterioration.

## **Social isolation and low physical activity**

The precise definition of SI varies across studies, but it generally refers to infrequent social contact. In a cross-sectional study with 8,688 adults, aged 52 and above, from the English Longitudinal Study of Ageing (ELSA)-wave two, SI increased the likelihood of lower self-reported leisure or occupational PA ( $B=0.12$ , 95% CI: 0.09 to 0.15) (Shankar et al., 2011). A smaller cross-sectional study using telephone-derived data also found a significant, but weak negative association between self-reported household and recreational PA and SI in 245 Australian adults with a mean age of 77 years ( $OR=1.04$ , 95% CI: 1.02 to 1.06) (Robins, Hill, Finch, Clemson, & Haines, 2018). Again, this evidence is limited due to reliance on self-reported PA. However, all studies showing an association between PA and either loneliness or SI have important limitations.

## **Limitations of the evidence**

All studies to date reporting an association between loneliness or SI and low levels of PA rely on self-reported PA, which is influenced by recall difficulty and social-desirability bias (Colbert, Matthews, Havighurst, Kim, & Schoeller, 2011). Only two studies included in the Pels and Kleinert (2016) review used objectively-measured PA. These did not support a relationship between loneliness and (a) higher step counts in a cross-sectional study with 238 adults aged 65 and above in the UK (Harris, Owen, Victor, Adams, & Cook, 2009) or (b) higher accelerometer counts in a two-year, longitudinal study with 228 Canadians aged 77 and above (Newall, Chipperfield, Bailis, & Stewart, 2013). Additionally, no PA intervention studies on older adults reviewed by Pels and Kleinert (2016) measured PA directly. Instead, they evaluated the difference in loneliness between the intervention and control groups (Hopman-Rock & Westhoff, 2002; Kahlbaugh, Sperandio, Carlson, & Hauselt, 2011; McAuley et al., 2000;

Savikko, Routasalo, Tilvis, & Pitkälä, 2010; Tse, Tang, Wan, & Vong, 2014). Thus, as also recognised by Pels and Kleinert (2016), it is not possible to conclude whether increased PA, or some other social factor, led to a reduction in loneliness in these interventions.

Furthermore, two recent systematic reviews highlighted that there is: (a) insufficient evidence in cross-sectional and prospective studies to evaluate whether or not loneliness or social support are associated with low PA (Smith, Banting, Eime, O'Sullivan, & van Uffelen, 2017), and (b) insufficient randomised-controlled-trial evidence to conduct a meta-analysis focussed on the effect of PA on loneliness or SI in older age (Shvedko, Whittaker, Thompson, & Greig, 2018a). Thus, there is a need for more good quality evidence on this association using objective PA measurement methods.

### **Types of physical activity**

Longitudinal evidence suggests that objectively-measured light PA (LPA) and moderate-to-vigorous PA (MVPA) are independently beneficial for older adults' functional and cardiovascular health (Sparling, Howard, Dunstan, & Owen, 2015). Increasing PA of any intensity (i.e. total PA [TPA]) has been associated with better physical health longitudinally (Fox et al., 2015; Simmonds et al., 2014) and is a PA promotion strategy highlighted in recently published PA guidelines for older adults (UK Government, 2019; US Department of Health and Human Services, 2018). It is therefore important to explore associations between loneliness or SI and these different quantifications of PA.

Everyday pursuits (e.g. shopping, socialising or volunteering) may also increase PA, as well as providing social (e.g. contact and support) and psychological (e.g. feelings of happiness or altruism) benefits (Eckert & Lange, 2015). For instance, each additional trip outdoors using active or public transport was associated with 11 additional minutes of MVPA in 240 adults

aged 70 and above (Davis et al., 2011b). The number of daily trips also correlated with step count ( $R=0.37$  to  $0.505$ ,  $p<0.001$ ) and with minutes of MVPA ( $R=0.37$  to  $0.472$ ,  $p<0.001$ ) (Davis et al., 2011a). From activity diaries, it was seen that these trips often involved social contact (Davis et al., 2011a). Measuring only self-reported intentional PA or exercise may miss out such forms of activity.

### **The rural context**

Rural areas in the UK are seeing greater population ageing than urban areas (Office for National Statistics, 2016), stressing the need for specific actions to improve health and well-being of older adults living in rural areas (Burholt & Scharf, 2013). Most research on PA, loneliness and SI in rural-living older adults has been conducted in the US or Australia (Barnett, Barnett, Nathan, Van Cauwenberg, & Cerin, 2017; Moran et al., 2014; Poscia et al., 2018). Such evidence may not translate to a UK rural context where geography, climate, culture, amenities and policies are different. Additionally, most research on SI and loneliness in rural areas of the UK is derived from data collected between 1979 and 1999 in rural North Wales (Wenger & Burholt, 2004) or Irish rural samples (Burholt & Scharf, 2013), or uses unstandardized measures of SI and loneliness (de Koning, Richards, & Stathi, 2016). These findings are, therefore, in need of updating.

### **Research aims**

1. To explore the association between objectively-measured PA and loneliness or SI from friends, family or neighbours.
2. To explore associations between specific activities out of the house and loneliness or SI from friends, family or neighbours.



## Research Methods

### Study Design

This cross-sectional study replicated the baseline data collection of the Older People and Active Living (OPAL) study, a longitudinal study of 240 urban-living adults aged 70 and above (Fox et al., 2011; Fox et al., 2015). This was done to create a dataset of rural-living older adults, comparable with that of OPAL's urban-living older population. OPAL's methods of seven-day accelerometry, questionnaires, a physical performance battery and a daily journey log were replicated. The current study adapted the questionnaire items on environmental perceptions and the daily journey log for use with a rural population. Ethical approval was received from the NHS Research Ethics Committee (reference number: 14/LO/0456) and the local NHS Research & Development committee (Reference: 2014/008).

### Sampling, selection and recruitment

The lead author recruited 112 older adults living across 23 rural villages or isolated dwellings in Wiltshire, South West England. These areas are defined as rural because they fall within a specified geographical area (Lower Super Output Areas) with fewer than 10,000 resident population (Office for National Statistics, 2013). In mid-2014 23% of residents in Wiltshire's rural villages and isolated dwellings were 65 years and over, compared with 18.6% in an average urban dwelling in England and Wales (Office for National Statistics, 2015).

Lower Super Output Areas with the lowest access to amenities were identified using the Index for Multiple Deprivation (IMD) from the 2010 Census (Department for Communities and Local Government, 2011).. The areas identified ranked among the top 40% of deprivation nationally and within Wiltshire (Supplementary Figure 1). National IMD ranks for income,

health deprivation and education were more favourable in the selected areas, while those for barriers to housing services and geographical barriers were much less favourable, compared with Wiltshire overall (Supplementary Table 1).

General practice (GP) patient lists were used for recruitment. These are the most complete sampling frames for older adults in given post code areas in the UK (more complete than electoral registers due to the necessity to register with a GP to receive free health care). Within the selected Lower Super Output Areas, three general practices were part of a clinical research network and had capacity to assist in research recruitment. These practices sent invitations to all patients who lived in rural post-code zones. Inclusion criteria were being aged 65 or over and community-dwelling. Exclusion criteria were a diagnosis of dementia, because of the potential challenges in providing full consent or accurately recalling daily pursuits, and the risk of emotional distress if asked about loneliness, judged by the GP.

We originally planned to combine data collected in this study with 150 rural-living respondents who participated in another study (McMurdo et al., 2012). To observe a one point change in the direct, three-level loneliness question ( $\alpha = 0.05$ ), 75 additional participant were necessary to achieve a combined sample of 225 participants. Assuming a 21% response rate from the initial invitations, as observed in the OPAL study (Fox et al., 2011), 450 invitations were sent across three general practices (150 invitations from each). However, the collaboration did not yield timely data, and by necessity we revised the recruitment target to satisfy the sample size needed for statistical analysis for objective 1. To test the individual prediction strength of three independent variables (LPA, MVPA and TPA) upon the dependent variables (SI types and loneliness), the standard approach recommended by Tabachnick and Fidell (2007) was applied ( $N \geq 104 + m$ , where  $m$  is the number of independent variables). Thus, the revised recruitment

target was a minimum of N=107, with an intention to over-recruit if the response-rate was higher than predicted.

## **Data Collection**

Two home visits were conducted seven to ten days apart. During the first visit consent was obtained, a physical function assessment administered, questionnaire part one completed and a waist-mounted accelerometer and activity diary delivered to be worn and completed over the next seven days. During the second visit, accelerometers and activity diaries were collected and questionnaire part two completed. The questionnaire was administered over two visits to reduce participant burden.

Ten members of a social group in a rural village within the recruitment zone, aged 65 or older (four men and six women), completed the questionnaire and activity diary and provided feedback on their interpretability and acceptability, before data collection commenced.

### **Objective physical activity.**

Waist-mounted Actigraph (GT3X) accelerometers were worn for seven consecutive days during waking hours (not in water), as done previously with older adults (Davis et al., 2011b; Harris et al., 2009; Jefferis et al., 2014; McMurdo et al., 2012). Data were extracted using the Actilife v6.11.2 software, and considered valid when available for at least 10 hours/day on five or more days. Three ordinal PA variables were computed: light PA (LPA), moderate-to-vigorous PA (MVPA) and total PA (TPA) using the Freedson, Melanson, and Sirard (1998) adult cut-off values (LPA: 100 to 1051 counts/minute, MVPA:  $\geq 1052$  counts/minute, TPA: any counts/minute over 100) accumulated in 1-minute bouts. MVPA was coded into categories of

'0 to 10 minutes', '11 to 20 minutes', '21 to 30 minutes', '31 to 40 minutes', '41 to 50 minutes', and '51 minutes+', as ten-minute bouts were widely used in health recommendations at the time (Department of Health, 2011). LPA and TPA were coded into categories of '0 to 120 minutes', '121 to 150 minutes', '151 to 180 minutes', '181 to 210 minutes' and '211 minutes+', as these categories allowed the distribution of these variables to be represented in five levels.

### **Specific activities.**

Participants recorded all specific activities out of the house, the time, reason and transport used for each activity into a seven-day diary, based on the OPAL study (Davis et al., 2011a; Fox et al., 2011). Rather than closed responses for specific activities, our study used open responses to capture diverse and new activities in a rural setting.

All diary responses were entered into an Excel spreadsheet, which was imported into the NVivo 10 software. The open responses were categorised into specific activities using inductive and deductive thematic analysis (Elo & Kyngäs, 2008; Hsieh & Shannon, 2005). Each open response was inductively described, creating 1005 individual 'nodes'. These were grouped into 62 lower-order themes. These lower-order themes were deductively matched to the specific activities used in the OPAL diaries. Ten of the OPAL higher-level categories matched the rural data, and six new categories were added (Supplementary File 1).

The lower- and higher-order categories of specific activities were given numerical codes, which were entered into new columns in the diary-data Excel spreadsheet. All diary quantitative variables were then imported into Stata 13.1. Ordinal variables were constructed detailing the weekly frequency of specific activities. The number of levels were restricted so that the last level contained at least 10 cases.

## **Loneliness.**

A single-item measure of loneliness (Yang & Victor, 2011) and the 3-item UCLA loneliness scale (University of California, Los Angeles) (Hughes, Waite, Hawkley, & Cacioppo, 2004) were included. Both measures were computed as binary variables to allow meaningful interpretation of logistic regression modelling outcomes.

For the single-item measure of loneliness *“How often do you feel lonely?”* the response category ‘hardly ever’ was coded as ‘not lonely’, and the categories ‘some of the time’ and ‘often’ were coded as ‘lonely’. This measure has been used extensively in research with older adults (Fokkema, De Jong Gierveld, & Dykstra, 2012; Losada et al., 2012; Luo & Waite, 2014; Tilvis et al., 2012; Yang & Victor, 2011). As it asks directly about loneliness it is easy to understand. However, responses might be influenced by social desirability bias from individuals who do not want to admit feeling lonely (Shiovitz-Ezra & Ayalon, 2012).

The 20-item UCLA loneliness scale has been widely used (Cacioppo, Hawkley, & Thisted, 2010; Hawkley et al., 2009; Steptoe, Owen, Kunz-Ebrecht, & Brydon, 2004). Its 3-item derivative, asking *“How often do you feel that you lack companionship?”*, *“How often do you feel left out?”* and *“How often do you feel isolated from others?”* with response categories of 1 ‘hardly ever’, 2 ‘some of the time’ and 3 ‘often’, the answers to which are summed into a score between 3 and 9, has good psychometric properties (Hughes et al., 2004). A score of four or above was coded as ‘lonely’ (indicating a response of ‘some of the time’ or ‘often’ to at least one question), and a score of three was coded as ‘not lonely’ (indicating responses of ‘none of the time’ to all questions). As this construct does not use the term ‘loneliness’ it may be less prone to social desirability bias (Shiovitz-Ezra & Ayalon, 2012).

### **Social isolation.**

Three SI variables were constructed using questions from the Social Capital Module (SCM) (Harper & Kelly, 2003): *'How often do you meet up with relatives who are not living with you?'*; *'How often do you meet up with friends?'*; and *'How often do you speak to neighbours face-to-face?'* The response categories were 1 'on most days', 2 'once or twice a week', 3 'once or twice a month' and 4 'less often than once a month'. Binary variables were coded for SI, according to the definition of 'isolated' being 'less than weekly direct contact with family, friends or neighbours' (Victor, Bond, & Bowling, 2003). These three questions for SI were assessed independently in this study leading to the creation of three variables: "SI from family"; "SI from friends"; and "SI from neighbours".

### **Control variables.**

Perceived physical and mental health, measured by the SF12v2 health-related quality of life scale (Cheak-Zamora, Wyrwich, & McBride, 2009), were selected as control variables because self-reported physical and mental health are strongly associated with SI, loneliness and PA in older adults (Cacioppo, Hughes, Waite, Hawkley, & Thisted, 2006; Victor & Bowling, 2012; Wenger & Burholt, 2004). The summary scores of physical health and mental health variables, generated by the SF12v2 software, were used as continuous scales (OPTUM, 2017). These predicted the original SF36 summary scores using data from general population surveys from nine European countries (Ware & Gandek, 1998), and had acceptable reproducibility in psychometric performance in a range of populations (Ware, Kosinski, & Keller, 1996).

Lower-limb physical function, measured by the Short Physical Performance Battery (SPPB), was used as a control variable. This includes three balance tests, a four-meter timed

walk, and a sit-to-stand test, providing a score between 0 and 12 (Guralnik et al., 1994). This is a valid and reliable test of older people's leg strength, balance and walking speed, with a high inter-rater reliability and test-retest reliability (Studenski et al., 2003).

Demographic control variables were also selected, including age (in bands: 65-69, 70-74, 75-79, 80-84, 85+), gender, ethnicity, education, household income, perceived financial difficulties, retirement status, home ownership and residence duration given their well-reported associations with PA, loneliness and SI (Bauman et al., 2012; Jivraj, Nazroo, & Barnes, 2012, 2016).

## Data Analysis

Logistic regression models were used because the dependent variables of interest, loneliness and social isolation, were dichotomous. Models were constructed using *Stata 13.1* to: (1) test whether PA is associated with loneliness or SI types, and (2) explore whether the frequency of different activities are associated with loneliness or SI types.

For analysis 1, SI types and loneliness measures were dependent variables, and the PA types were independent variables in logistic regression models. For each SI type or loneliness measure, three models were constructed: one with LPA; one with MVPA; one with TPA as the independent variable, with control variables added simultaneously. For each regression model an LR-contribution test was applied to assess whether the addition of LPA, MVPA or TPA increased the model's ability to predict SI type or loneliness, in comparison to the model with only the control variables as predictors. As this analysis included multiple testing of fifteen relationships, the Bonferroni correction was applied (Bender & Lange, 2001) and an adjusted p-value threshold of  $0.05/15 = p < 0.003$  used to interpret the statistical significance of associations.

For analysis 2, SI types and two loneliness measures were the dependent variables, and the frequency of specific activities were the independent variables. Non-parametric Spearman correlation tests were applied, as the data were non-normally distributed, to identify which activities correlated with SI types and loneliness measures. Only the activities which correlated significantly with a SI type or loneliness measure were subsequently tested in regression models. For each SI type and loneliness measure, multiple logistic regression models were constructed, each including one of the correlated activity type variables, and all control variables. If more than one activity type variable remained significant in this model, the variables were checked for inter-collinearity using non-parametric correlation tests (defining collinearity as  $r > 0.7$ ) and, if not collinear, were added into a model simultaneously, along with the control variables. Acceptable statistical significance was set at  $p < 0.05$  level. In a methodological review, Bender and Lange (2001) argued that the Bonferroni correction is too conservative for exploratory analyses which seek to generate hypotheses rather than test them. Although there is a risk of a type II error due to multiple testing in this second analysis, it was deemed unnecessary to apply a statistical correction given its exploratory nature.

## Findings

### Sample Characteristics

The sample comprised 112 older adults from 23 villages or hamlets in Wiltshire. The mean age was 72.8 (SD 6.6) years (range 65 to 95 years) and 51.8% were women (Table 1). The recruitment rate was 25%.

SI from family was reported by 69.6%, SI from friends by 34.8%, SI from neighbours by 16.1% of participants while 7.1% reported isolation from family, friends and neighbours at the same time (Figure 1). Using the single-question loneliness measure, 24.1% reported loneliness



(19.6% 'some of the time' and 4.5% 'often'). Using the UCLA loneliness scale, 39.3% reported loneliness (a score of  $\geq 4$ ). There were no gender or age differences in SI types or loneliness.

Valid accelerometer data was attained from 106 participants (50.9% female, mean age 72.8, SD 6.6 years). Participants engaged in a daily mean LPA of 3.0 hours (SD 1.1), MVPA of 32.3 minutes (SD 25.6), and TPA of 3.5 hours (SD 1.3). Women spent more time in LPA than men ( $p < 0.01$ ), but did not differ in MVPA or TPA. Across the five age categories, LPA ( $p < 0.05$ ), MVPA ( $p < 0.001$ ) and TPA ( $p < 0.001$ ), were significantly different, with a trend in older participants taking less PA.

Table 1. Demographic characteristics of the sample

Variable	Response categories	Frequency (%)	Gender difference (p-values)	Age difference (p-values)
<b>Age</b> (Mean 72.8, SD 6.6)	65 to 69 years	50 (44.6)	0.78	NA
	70 to 74 years	23 (20.5)		
	75 to 79 years	19 (17.0)		
	80 to 84 years	14 (12.5)		
	85+ years	6 (5.4)		
<b>Sex</b>	Female	58 (51.8)	NA	0.96
<b>Physical function</b> (SPPB)	Low (1-6)	7 (6.2)	0.47	<0.001 <sup>1</sup>
	Mid (7-9)	26 (23.2)		
	High (10-12)	79 (70.5)		
<b>Ethnicity</b>	White/Caucasian	112 (100.0)	NA	NA
<b>Marital status</b>	Married/in relationship	82 (73.2)	0.001 <sup>2</sup>	0.03 <sup>2</sup>
	Widowed (living alone)	21 (18.8)		
	Single/separated (living alone)	9 (8.0)		
<b>Education achieved</b>	Middle school	2 (1.8)	0.07	0.10
	Some secondary school	3 (2.7)		
	Completed secondary school	27 (24.1)		
	Some college/vocational training	35 (31.3)		

	Completed Tertiary education	45 (40.2)		
<b>Household income</b>	More than £30,000	40 (35.7)	0.03 <sup>3</sup>	<0.001 <sup>3</sup>
	£20-30,000	27 (24.1)		
	£10-20,000	30 (26.8)		
	£5-10,000	9 (8.0)		
	Under £5,000	3 (2.7)		
	Don't know	1 (0.9)		
	Missing response	2 (1.8)		
<b>Retirement status</b>	Retired	86 (76.8)	0.51	0.98
	Working part time/casual hours	21 (18.8)		
	Working full time	5 (4.5)		
<b>House ownership</b>	Own/buying/free stay	95 (84.8)	0.11	0.60
	Rent	17 (15.2)		
<b>Residence duration</b> (Mean 22.2, SD 12.4)	0 to 9 years	25 (22.3)	0.35	0.31
	10 to 19 years	26 (23.2)		
	20 to 29 years	31 (27.7)		
	30 to 39 years	21 (18.8)		
	40 to 59 years	9 (8.0)		

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<sup>1</sup>Older age groups have significantly lower physical function; <sup>2</sup>More women and older participants were single or widowed; <sup>3</sup> More women and older participants reported lower household incomes.

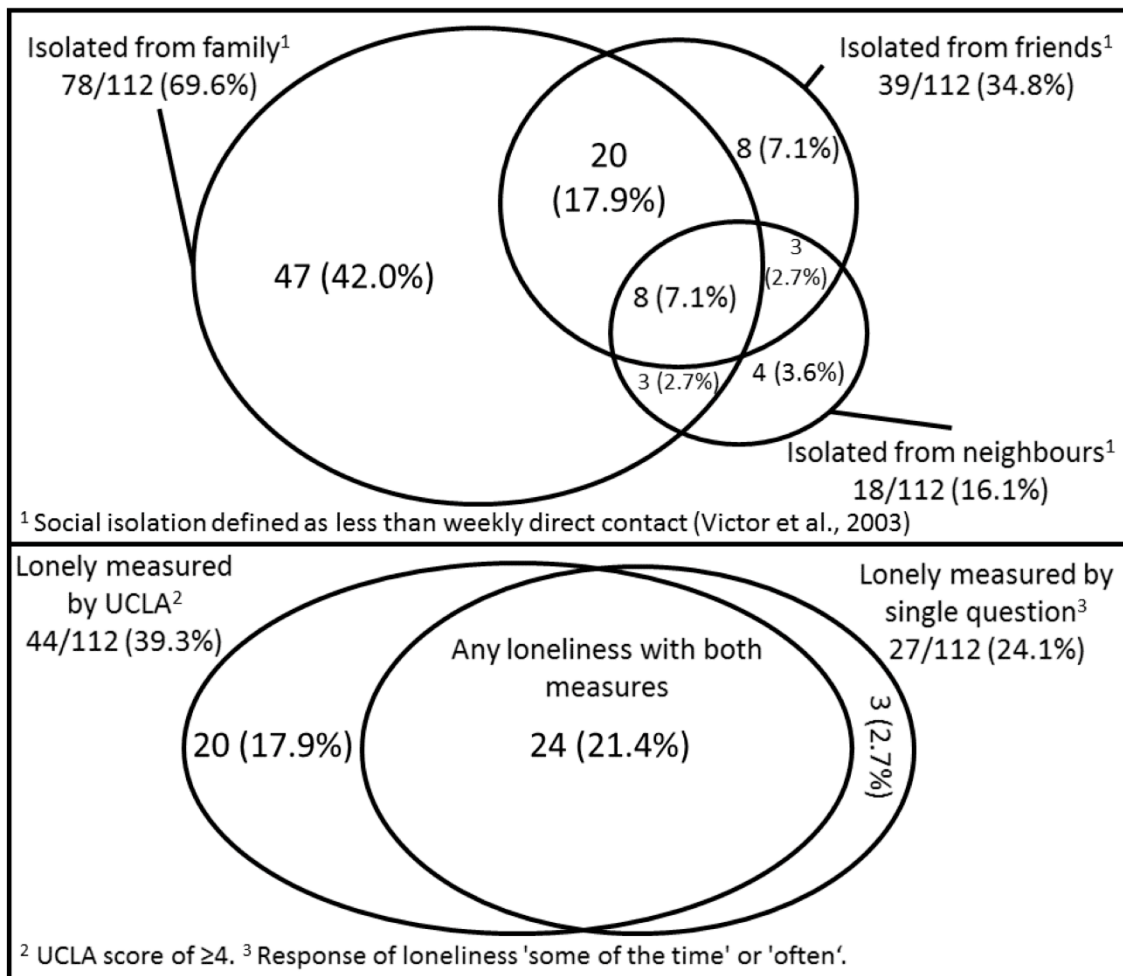


Figure 1. Representation of overlap between SI types and loneliness measures

## Specific Activities

Sixteen specific activities were derived from the activity diaries. Ten matched the OPAL study –derived categories: shopping, visits/social events, entertainment, personal/household errands, accompanying others, sports/exercise, health-related activities, day trips, hobbies (non-PA) and religious activities. Six additional activities were identified: walking for leisure or exercise, dog walking, volunteering, paid work, gardening, do-it-yourself (DIY) tasks in the garden or driveway. The frequency of total daily trips correlated with minutes of LPA ( $r=0.43$ ,  $p<0.001$ ), MVPA ( $r=0.41$ ,  $p<0.001$ ) and TPA ( $r=0.49$ ,  $p<0.001$ ).

### **Analysis 1. Is PA Associated With Loneliness or Types of SI?**

The single-question loneliness measure and UCLA loneliness scale were not correlated with LPA, MVPA or TPA (Supplementary table 2). Consistent with this, in controlled regression models, none of the PA variables decreased the likelihood of either loneliness variables ( $p < 0.003$ ) (Table 2, Supplementary Table 4). LPA, MVPA and TPA also did not make significant contributions to regression models predicting the single-question loneliness measure (LPA: LR  $\chi^2 = 0.14$ ,  $p = 0.71$ ; MVPA: LR  $\chi^2 = 1.52$ ,  $p = 0.22$ ; TPA: LR  $\chi^2 = 0.03$ ,  $p = 0.87$ ) or UCLA loneliness scale (LPA: LR  $\chi^2 = 0.16$ ,  $p = 0.69$ ; MVPA: LR  $\chi^2 = 0.17$ ,  $p = 0.68$ ; TPA: LR  $\chi^2 = 0.44$ ,  $p = 0.51$ ).

The three SI variables were not correlated with LPA, MVPA or TPA (Supplementary Table 1). In adjusted regression models, none of the PA variables decreased the likelihood of SI from family, friends or neighbours in a continuous manner ( $p < 0.003$ ) (Table 2), nor when each ordinal level of PA variables was compared to the base category (Supplementary Table 5). None of the PA variables made a significant contribution to the regression models predicting SI types ( $p < 0.003$ ): SI from family (LPA: LR  $\chi^2 = 6.85$ ,  $p = 0.009$ ; MVPA: LR  $\chi^2 = 1.64$ ,  $p = 0.20$ ; TPA: LR  $\chi^2 = 7.38$ ,  $p = 0.007$ ); SI from friends (LPA: LR  $\chi^2 = 0.25$ ,  $p = 0.62$ ; MVPA: LR  $\chi^2 = 0.03$ ,  $p = 0.87$ ; TPA: LR  $\chi^2 = 0.00$ ,  $p = 0.99$ ); SI from neighbours (LPA: LR  $\chi^2 = 0.75$ ,  $p = 0.39$ ; MVPA: LR  $\chi^2 = 3.60$ ,  $p = 0.06$ ; TPA: LR  $\chi^2 = 2.86$ ,  $p = 0.09$ )

1 Table 2. Multivariate regression outcomes for LPA, MVPA and TPA as predictors of loneliness and types of social isolation

	Loneliness (direct)		Loneliness (UCLA)		SI from family		SI from friends		SI from neighbours	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
<b>LPA 30-min. incr.</b>	1.07	0.75, 1.52	0.93	0.67, 1.30	<b>0.65*</b>	<b>0.46, 0.91</b>	1.08	0.79, 1.48	0.85	0.58, 1.24
<b>Control variables:</b>										
Widowed	9.59**	2.01, 45.68	5.09*	1.07, 24.19	0.21*	0.05, 0.82	0.30	0.06, 1.61	1.43	0.26, 7.75
Older age (years)	1.01	0.91, 1.12	0.89*	0.80, 0.99	0.96	0.88, 1.05	1.03	0.94, 1.12	0.89	0.79, 1.01
Household income	1.33	0.70, 2.52	1.15	0.65, 2.00	1.57	0.93, 2.64	1.44	0.86, 2.40	1.03	0.56, 1.90
Residence years	1.00	0.96, 1.04	1.00	0.96, 1.04	0.97	0.94, 1.01	0.97	0.94, 1.01	1.00	0.96, 1.04
Physical function	1.26	0.79, 2.01	0.76	0.52, 1.11	0.99	0.65, 1.50	0.89	0.63, 1.25	0.75	0.50, 1.13
SF-12 PCS <sup>1</sup>	1.01	0.98, 1.05	1.01	0.98, 1.04	1.00	0.97, 1.03	0.98	0.95, 1.00	1.01	0.98, 1.04
SF-12 MCS <sup>2</sup>	0.94**	0.90, 0.98	0.89***	0.84, 0.95	0.98	0.94, 1.02	1.05	1.00, 1.09	1.00	0.96, 1.05
<b>MVPA 10-min. incr.</b>	1.26	0.87, 1.83	0.93	0.66, 1.31	0.81	0.58, 1.13	0.97	0.71, 1.33	0.70	0.48, 1.02
<b>Control variables:</b>										
Widowed	10.22**	2.11, 49.48	5.31*	1.14, 24.69	0.34	0.09, 1.19	0.29	0.05, 1.51	1.41	0.27, 7.46
Older age (years)	1.04	0.93, 1.16	0.88*	0.78, 0.99	0.95	0.86, 1.05	1.02	0.92, 1.12	0.85*	0.74, 0.98
Household income	1.35	0.71, 2.57	1.16	0.67, 2.03	1.64	1.00, 2.71	1.40	0.85, 2.30	1.01	0.55, 1.87
Residence years	1.00	0.96, 1.04	1.00	0.96, 1.04	0.98	0.95, 1.02	0.97	0.94, 1.01	1.00	0.96, 1.05
Physical function	1.28	0.80, 2.07	0.76	0.52, 1.11	0.98	0.66, 1.46	0.89	0.63, 1.26	0.73	0.48, 1.13
SF-12 PCS	1.01	0.98, 1.04	1.01	0.98, 1.05	1.00	0.97, 1.03	0.98	0.95, 1.01	1.02	0.98, 1.06
SF-12 MCS	0.94**	0.90, 0.98	0.89***	0.84, 0.95	0.99	0.95, 1.03	1.04	1.00, 1.09	1.00	0.96, 1.04

<b>TPA 30-min. incr.</b>	0.98	0.72, 1.33	0.90	0.67, 1.22	<b>0.66*</b>	<b>0.47, 0.91</b>	1.00	0.76, 1.32	0.75	0.54, 1.05
<b>Control variables:</b>										
Widowed	8.79**	1.89, 40.80	4.85*	1.02, 23.13	0.22*	0.05, 0.89	0.28	0.05, 1.51	1.23	0.23, 6.67
Older age (years)	1.01	0.91, 1.12	0.88*	0.79, 0.99	0.93	0.84, 1.03	1.02	0.93, 1.12	0.87*	0.76, 0.99
Household income	1.30	0.69, 2.47	1.13	0.64, 1.98	1.51	0.90, 2.53	1.40	0.84, 2.32	0.97	0.52, 1.81
Residence years	1.00	0.96, 1.04	1.00	0.96, 1.04	0.98	0.95, 1.02	0.97	0.94, 1.01	1.00	0.96, 1.05
Physical function	1.27	0.80, 2.03	0.76	0.52, 1.12	0.97	0.64, 1.48	0.89	0.63, 1.26	0.75	0.49, 1.15
SF-12 PCS	1.02	0.98, 1.05	1.01	0.98, 1.05	1.01	0.98, 1.04	0.98	0.95, 1.01	1.02	0.98, 1.05
SF-12 MCS	0.94**	0.90, 0.98	0.89***	0.84, 0.95	0.97	0.93, 1.02	1.04	1.00, 1.09	0.99	0.95, 1.04

\*p<0.05, \*\*p<0.01. \*\*\*p<0.001 (shown in bold for independent variable). <sup>1</sup> Physical component score of health-related quality of life, <sup>2</sup> Mental Component Score of health-related quality of life. Note: Odds Ratio's under 1.00 indicate that the likelihood of loneliness or social isolation is lower for an increased level of PA (30-min increase for LPA and TPA, 10-min increase for MVPA). Odds Ratio's over 1.00 indicate that the likelihood of loneliness or social isolation is higher for an increased level of PA.

## **Analysis 2. Are Activities Associated With Loneliness or Types of SI?**

None of the specific activity variables correlated inversely to the one-question loneliness measure or UCLA loneliness scale. The UCLA loneliness scale did correlate positively with frequency of religious activities ( $r = 0.25$ ,  $p < 0.01$ ) (i.e. being lonely correlated with more religious activities) (Supplementary Table 3). These associations were not pursued in regression models.

Significant inverse correlations were observed between: a) SI from friends and hobbies ( $r = -0.34$ ,  $p < 0.001$ ), sports/exercise ( $r = -0.26$ ,  $p < 0.01$ ) and religious activities ( $r = -0.194$ ,  $p < 0.05$ ); b) SI from neighbours and volunteering ( $r = -0.29$ ,  $p < 0.01$ ); and c) SI from family and accompanying others ( $r = -0.28$ ,  $p < 0.01$ ) (Supplementary Table 3). In controlled regression models, more frequent volunteering decreased the likelihood of SI from neighbours (OR=0.23,  $p < 0.05$ , 95% CI: 0.06 to 0.91), more frequent accompanying of others decreased the likelihood of SI from family (OR=0.39,  $p < 0.01$ , 95% CI: 0.22 to 0.68), and more frequent sports/exercise decreased the likelihood of SI from friends (OR=0.56,  $p < 0.01$ , 95% CI: 0.33 to 0.97) (Table 3). Hobby and religious activities did not predict any SI type in the multivariate regression models.

Table 3. Multivariate regression outcomes for reasons for trips as predictors of different types of social isolation.

	SI from friends		SI from neighbours		SI from family	
	OR	95% CI	OR	95% CI	OR	95% CI
<b>Reasons for trips</b>						
Sports/exercise	0.56*	0.33, 0.97				
Hobbies	0.50	0.24, 1.05				
Religion	0.29	0.08, 1.09				
Volunteering			0.23*	0.06, 0.91		
Accompanying others					0.39**	0.22, 0.68
<b>Control variables</b>						
Female	0.98	0.38, 2.54	1.26	0.39, 4.03	0.47	0.16, 1.36
Older age (years)	0.96	0.88, 1.05	0.90	0.81, 1.00	0.95	0.87, 1.04
Widowed	0.36	0.08, 1.73	1.34	0.29, 6.09	0.22*	0.06, 0.85
Residence years	0.98	0.94, 1.02	0.98	0.94, 1.03	0.97	0.94, 1.01
Physical function	0.90	0.61, 1.34	0.72	0.47, 1.10	0.86	0.57, 1.29
SF-12 PCS <sup>1</sup>	0.98	0.95, 1.01	1.01	0.98, 1.05	1.01	0.98, 1.04
SF-12 MCS <sup>2</sup>	1.04	1.00, 1.09	0.99	0.95, 1.03	0.98	0.94, 1.02

\*p<0.05, \*\*p<0.01; <sup>1</sup>Physical Component Score; <sup>2</sup>Mental Component Score. Note: Odds Ratio's under 1.00 indicate that the likelihood of social isolation is lower for each additional trip made for that reason. Odds Ratio's over 1.00 indicate that the likelihood of social isolation is higher for each additional trip made for that reason.

## Discussion

This study explored the associations between objectively-measured PA, specific activities, loneliness and SI in rural-living older adults in England. No evidence was found for the association between objectively-measured PA, SI and loneliness. Associations were found between frequency of volunteering, accompanying others, and sports/exercise and lower odds of SI from neighbours, family or friends, respectively. Our findings are consistent with the results of other studies using objectively-measured PA in older UK and Canadian



populations (Harris et al., 2009; Newall et al., 2013). Our findings are not, however, consistent with cross-sectional and longitudinal studies employing self-reported measures of PA in middle to older-age (Hawkley et al., 2009; Netz et al., 2013; Shankar et al., 2011).

The difference in findings may relate to a possible effect of low mood on self-reporting PA. Hawkley et al. (2009) concluded that poor self-regulation of emotion and diminished hedonic regulation seen in those who are lonely, mediated the association between loneliness and lower self-reported PA in 229 adults aged 50 to 68 years. Loneliness at baseline has also been linked to depression at follow-up measures in longitudinal studies (Cacioppo et al., 2010; Jaremka et al., 2014). Thus, lonely individuals may be more likely to have cognitive styles of processing that lead to the under-reporting of their levels of PA compared with non-lonely individuals.

Given our findings, the theory that loneliness leads to poorer long-term physical health through the mechanism of reduced PA (Hawkley & Cacioppo, 2010) may need to be revisited. While longitudinal evidence suggests that loneliness is associated with poorer long-term physical health in older adults (Holt-Lunstad et al., 2015; Shankar et al., 2017; Valtorta et al., 2016), this may be due to reasons other than objective levels of PA. For instance, raised blood pressure, stress hormones and behaviours such as smoking and alcohol use have also been associated with loneliness and may be more promising mediators of its association with long-term health (Elovainio et al., 2017; Hackett, Hamer, Endrighi, Brydon, & Steptoe, 2012). If, as our findings suggest, loneliness is not associated with objectively-measured physical inactivity, there could be physically active older adults who do suffer from loneliness. There is a need for research to identify such individuals and explore the context in which this might occur.

The lack of association between objectively-measured PA and types of SI is not consistent with findings from a large UK-based longitudinal study (Shankar et al., 2011). This difference might be explained by a difference in SI definitions. Shankar et al. (2011) used a definition including 'participation in social activities', which is perhaps an inherently active type of social contact. Our study's SI definition includes only contact frequency, which could occur at home or during non-active pursuits. Additionally, Shankar et al. (2011) used self-reported leisure-time PA, while our study used accelerometer data, which captures the daily lifestyle of older people more accurately. Objectively-measured PA includes all PA, accrued in isolation or with others, whereas self-reported leisure-time PA includes, for the large part, participation in leisure or sport activities, which often include social contact (Colbert et al., 2011).

Nevertheless, in the exploratory analysis some specific activities were associated with a lower likelihood of SI. Volunteering, accompanying others and sports/exercise often include social contact and may therefore contribute to the avoidance of SI. It is interesting, however, that these pursuits were not associated with a lower likelihood of loneliness. This adds support to the cognitive theory of loneliness that it is the individual's expectations for, and evaluations of, quality of social contact that influence levels of loneliness and not the frequency of social contact (Perlman & Peplau, 1981).

Interventions based on volunteering/accompanying others have led to increases in activities outside the home (Stathi et al., 2019) and increases in daily steps in older adults living in urban settings (Varma et al., 2016). Active ageing interventions have additional social benefits as a result of the exercise engagement (Martin & Woods, 2012; Stathi, McKenna, & Fox, 2010). Thus, PA/exercise and/or volunteering/accompanying-based interventions may improve both PA and frequency of social contact with neighbours and friends for older people

in rural settings (Jenkinson et al., 2013; Moore, Warburton, O'Halloran, Shields, & Kingsley, 2016). However, without addressing issues related to the individual person's evaluation of quality of social contact, such interventions might not be able to support the reduction in feelings of loneliness.

The 4.5% of participants feeling 'often' lonely and 19.6% feeling lonely 'some of the time' reported in this study, appear lower than observed in nationally-representative UK data from the Omnibus Survey of 999 older adults (9% and 30%, respectively) (Victor & Bowling, 2012) and in 1,255 older adults in a metropolitan area (7.7% and 38.3%, respectively) (Dahlberg & McKee, 2014). In contrast, the 7.1% of participants in our study reporting SI from friends, family and neighbours, appears higher than the 5% observed in the nationally-representative ELSA data (Jivraj et al., 2012). However, it is difficult to make direct comparisons with the datasets due to differences in methodology of assessing loneliness and SI.

Our findings of more women involved with LPA are consistent with the findings of a study with 240 city-dwelling UK older adults (Davis et al., 2011b). However, in our rural data, women did not differ in MVPA from men, while the urban-living older men engaged in more MVPA than women. The urban men and women spent, on average,  $22.6 \pm 18.3$  and  $14.3 \pm 18.3$  minutes in MVPA, respectively (Davis et al., 2011b), while this was  $32.0 \pm 26.7$  and  $32.6 \pm 24.7$  minutes for men and women, respectively, in our rural data. This could indicate a higher mean level of MVPA due to a rural lifestyle for older adults, compared with urban areas. However, this should be interpreted with caution as the SD was large, suggesting wide variation in MVPA within our rural sample.

## Strengths and Limitations

A strength of this study is the use of accelerometer-derived PA data, which is not influenced by recall difficulties, emotional state and social-desirability bias (Colbert et al., 2011; Strath et al., 2013). Our study used accelerometer cut-points developed by Freedson et al. (1998) to determine the amount of time spent in LPA, MVPA and TPA. These cut points were developed in a sample of young adults (mean age 23), and may not accurately reflect the relative intensity of PA experienced by older adults (Sun, Norman, & While, 2013). Appropriate cut-points for older adults is still a developing area in the literature.

The recruitment through letters posted directly to individuals by their General Practitioner may have increased our reach to isolated individuals, who might not respond to a community poster or a snow-ball recruitment. However, given the cognitive style associated with feelings of loneliness, it remains possible that those most lonely may still not have responded. For ethical reasons, we were unable to access descriptive data on the demographic profile of the 450 people invited by the GPs. Therefore, we cannot know how representative the sample was of all who were invited.

While we sampled from 23 rural villages across Wiltshire, giving a wide social and geographical diversity, the sample was exclusively white-Caucasian and, on average, affluent and highly educated. This leads to limited generalisability to rural areas outside South West UK, including more ethnically diverse areas and areas of high socio-economic deprivation (Office for National Statistics, 2016d). The low mean age and the high income and education levels of our rural sample may also have contributed to the low loneliness and high MVPA levels when compared to urban or nationally-representative data (Supplementary Table 1) (Demakakos, Nunn, & Nazroo, 2006; Dollman, Hull, Lewis, Carroll, & Zarnowiecki, 2016; Fokkema et al., 2012).

The small sample size could have allowed outliers to exert a strong influence on the regression outcomes. This may explain the wide confidence intervals seen in Supplementary Tables 4 and 5 (Tabachnick & Fidell, 2007). Due to the cross-sectional nature of the dataset, we cannot make assumptions about causality or the direction of relationships. However, this is the first study to use seven days of objectively-measured PA and to measure SI and loneliness in a UK-based rural older sample. Therefore, the associations and lack of associations observed make a useful contribution to further, larger-scale research on the topic.

## **Conclusions**

This study did not find an association between loneliness or three types of SI and lower daily minutes of light, moderate-to-vigorous and total PA, measured objectively. In a sample of 112 older adults, weekly frequency of volunteering, accompanying others and sports/exercise did reduce the likelihood of SI from neighbours, family and friends, respectively, for rural-living older adults. Future studies should replicate this analysis in a larger, more diverse sample of older adults, using accelerometer cut-points chosen to match older-adults' physiological demands for certain movements (Stamatakis et al., 2019). Intervention studies employing volunteering, accompanying others and sports/exercise activities may prove fruitful in rural areas to reduce SI in older adults.

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Supplementary Table 1. National rank of IMD and IMD sub-scales (Mean  $\pm$  SD)

	IMD	Income	Health deprivation	Education	Barriers to housing and services	Geographical Barriers
<b>England</b>	<b>16241</b>	<b>16241</b>	<b>16241</b>	<b>16241</b>	<b>16241</b>	<b>16241</b>
	$\pm 9377$	$\pm 9377$	$\pm 9377$	$\pm 9377$	$\pm 9377$	$\pm 9377$
<b>Wiltshire</b>	<b>22229</b>	<b>21551</b>	<b>23015</b>	<b>18884</b>	<b>14401</b>	<b>10264</b>
	$\pm 6833$	$\pm 7161$	$\pm 6570$	$\pm 8402$	$\pm 9344$	$\pm 8486$
<b>Recruited areas</b>	<b>18314</b>	<b>22263</b>	<b>25362</b>	<b>21178</b>	<b>1436</b>	<b>824</b>
	$\pm 1976$	$\pm 2809$	$\pm 2753$	$\pm 2771$	$\pm 1034$	$\pm 614$

Note: A lower rank indicates greater deprivation in IMD and IMD sub-scales.

Supplementary Table 2. Spearman correlation outcomes between physical activity variables and loneliness and SI types.

PA types (mean/day)	Loneliness (Direct)	Loneliness (UCLA)	SI <sup>1</sup> from friends	SI from neighbours	SI from family
Light PA (30-min. incr.)	0.032	0.033	-0.122	-0.104	-0.136
MVPA <sup>2</sup> (10-min. incr.)	0.083	0.002	-0.083	-0.104	0.005
Total PA (30min. incr.)	0.031	0.039	-0.124	-0.125	-0.073

<sup>1</sup> SI= social isolation. <sup>2</sup> Moderate-to-vigorous physical activity. Note: negative correlations indicate that more of this types of PA reduced the likelihood of loneliness or social isolation, although none achieved statistical significance at the  $p < 0.05$  level.

Supplementary Table 3. Spearman correlation outcomes between social isolation types, loneliness variables and frequency of everyday activities.

Everyday pursuits (weekly frequency)	Loneliness (Direct)	Loneliness (UCLA)	SI <sup>1</sup> from friends	SI from neighbours	SI from family
<b>Hobbies</b>	-0.008	-0.121	<b>-0.341***</b>	-0.059	0.088
<b>Sports/exercise</b>	0.119	-0.100	<b>-0.260**</b>	-0.104	0.005
<b>Religion</b>	0.126	<b>0.251**</b>	<b>-0.194*</b>	-0.038	-0.182
Visiting	-0.009	-0.120	-0.137	-0.096	-0.151
<b>Volunteering</b>	-0.070	-0.012	-0.112	<b>-0.287**</b>	0.045
Gardening	-0.049	-0.047	-0.078	-0.110	-0.034
Around house DIY	0.029	-0.055	-0.038	-0.104	0.103
Shopping	0.119	0.050	-0.034	-0.150	-0.064
Entertainment	-0.064	-0.119	-0.029	-0.074	-0.041
Dog walking	-0.023	0.038	0.022	-0.017	0.044
Holiday/day trips	-0.090	-0.077	0.028	0.162	-0.003
Leisure/exercise					
walking	0.133	0.131	0.035	-0.047	0.084
Health-related trips	0.028	0.173	0.040	-0.037	-0.077
<b>Accompanying others</b>	-0.081	0.014	0.045	-0.028	<b>-0.279**</b>
Personal business	-0.087	-0.095	0.046	-0.017	-0.001
Paid work	-0.038	-0.179	0.107	-0.134	0.008

\*p<0.05, \*\*p<0.01, \*\*\*p<0.001 (shown in bold). <sup>1</sup> SI= social isolation. Note: negative correlations indicate that participation in activities reduced the degree of loneliness or social isolation.

Supplementary Table 4. Multivariate regression outcomes for ordinal variables of LPA, MVPA and TPA predicting two measures of loneliness.

	Direct loneliness		UCLA loneliness	
	OR	95% CI	OR	95% CI
<b>LPA (ref: &lt; 120 min)</b>				
120 to 149 min	0.56	0.09, 3.66	1.33	0.22, 8.05
150 to 179 min	2.92	0.39, 22.09	5.08	0.72, 35.95
180 to 209 min	0.87	0.12, 6.54	1.44	0.21, 9.75
≥ 210 min	1.21	0.15, 9.46	0.72	0.08, 6.16
<b>Control variables</b>				
Widowed	10.77**	2.16, 53.69	6.63*	1.27, 34.70
Older age (years)	1.00	0.90, 1.12	0.88*	0.79, 0.99
Household income	1.16	0.60, 2.24	1.10	0.61, 1.98
Residence years	1.01	0.96, 1.05	1.00	0.96, 1.05
Physical function	1.13	0.68, 1.87	0.64*	0.41, 0.99
SF-12 PCS <sup>1</sup>	1.02	0.99, 1.06	1.02	0.99, 1.06
SF-12 MCS <sup>2</sup>	0.93**	0.89, 0.98	0.88***	0.82, 0.94
<b>MVPA (ref: &lt; 10 min)</b>				
10 to 19 min	2.55	0.20, 32.37	5.09	0.52, 50.02
20 to 29 min	6.28	0.36, 110.36	6.76	0.55, 82.60
30 to 39 min	1.03	0.06, 18.16	1.79	0.15, 22.18
40 to 49 min	14.70	0.94, 228.79	6.34	0.46, 86.43
≥ 50 min	6.35	0.40, 101.38	2.13	0.19, 23.90
<b>Control variables</b>				
Widowed	11.05**	2.06, 59.34	6.05*	1.13, 32.40
Older age (years)	1.08	0.95, 1.23	0.88	0.77, 1.00
Household income	1.31	0.66, 2.61	1.21	0.66, 2.20
Residence years	0.99	0.95, 1.04	0.99	0.95, 1.04
Physical function	1.26	0.71, 2.24	0.61	0.38, 1.00
SF-12 PCS	1.01	0.97, 1.05	1.01	0.98, 1.04
SF-12 MCS	0.93**	0.89, 0.98	0.90**	0.84, 0.96
<b>TPA (ref: &lt; 120 min)</b>				
120 to 149 min	0.27	0.01, 7.00	8.16	0.61, 109.02

150 to 179 min	0.48	0.03, 7.97	3.80	0.19, 76.89
180 to 209 min	2.47	0.23, 27.05	5.90	0.51, 68.73
210 to 239 min	1.43	0.13, 15.72	3.67	0.33, 41.35
240 to 269 min	0.22	0.01, 4.33	7.11	0.51, 98.54
≥ 270 min	0.96	0.08, 11.55	1.07	0.08, 13.55
<b>Control variables</b>				
Widowed	16.67**	2.65, 104.75	9.18*	1.32, 63.84
Older age (years)	1.01	0.89, 1.13	0.87*	0.77, 0.99
Household income	1.32	0.67, 2.61	1.39	0.73, 2.64
Residence years	1.01	0.96, 1.05	1.00	0.96, 1.04
Physical function	1.22	0.72, 2.05	0.61*	0.38, 0.98
SF-12 PCS	1.02	0.98, 1.06	1.02	0.99, 1.06
SF-12 MCS	0.94**	0.89, 0.98	0.87***	0.81, 0.94

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\*p<0.05, \*\*p<0.01. \*\*\*p<0.001. <sup>1</sup> Physical component score, <sup>2</sup> Mental Component Score. Note: Odds Ratio's under 1.00 indicate that the likelihood of loneliness is lower for that given response category, compared with the reference category. Odds Ratio's over 1.00 indicate that the likelihood of loneliness is higher for that given response category, compared with the reference category.

Supplementary Table 5. Multivariate regression outcomes for ordinal variables of LPA, MVPA and TPA predicting SI from family, SI from friends and SI from neighbours

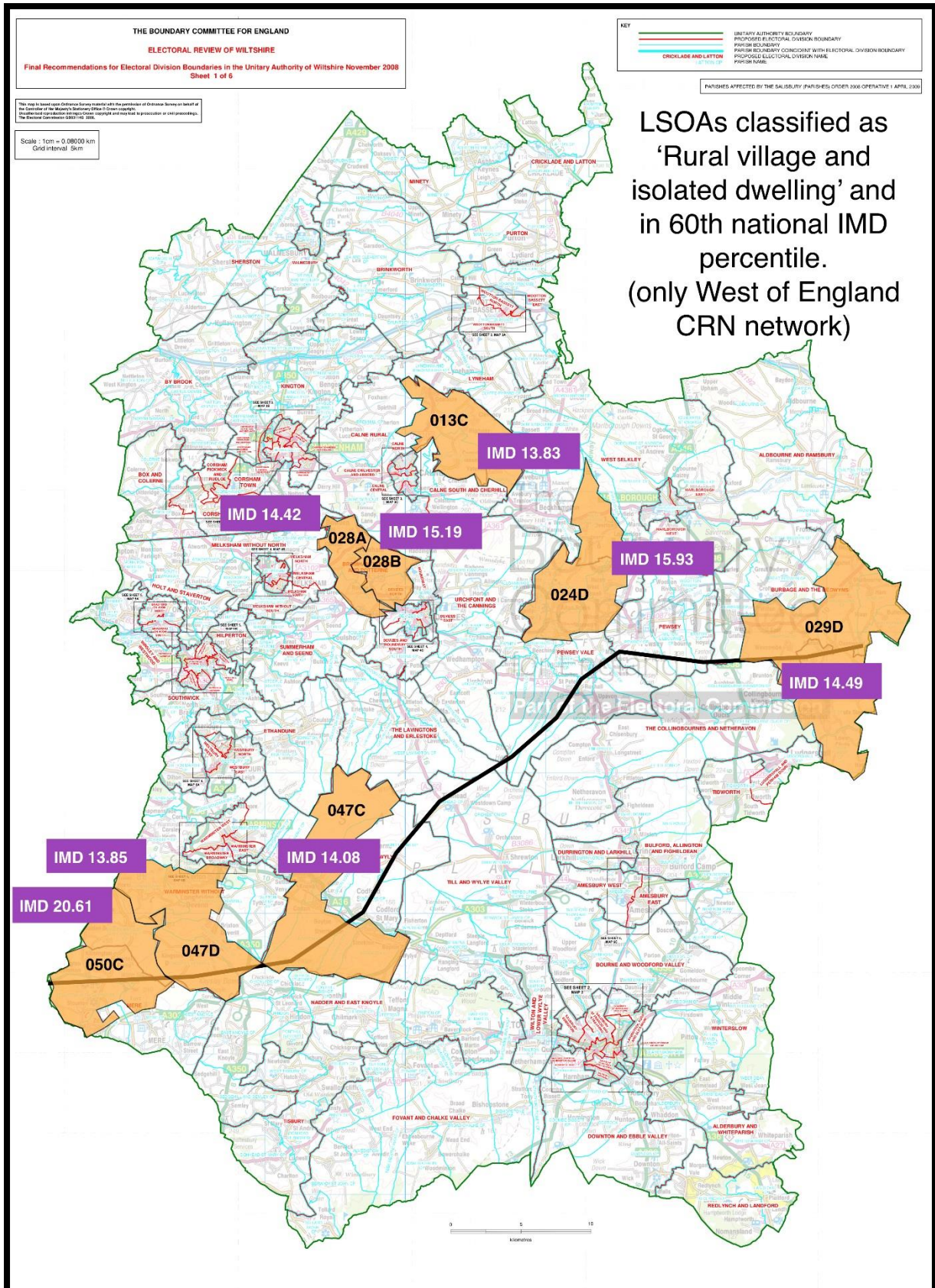
	SI from family		SI from friends		SI from neighbours	
	OR	95% CI	OR	95% CI	OR	95% CI
<b>LPA (ref: &lt; 120 min)</b>						
120 to 149 min	0.46	0.08, 2.50	<b>6.91*</b>	<b>1.05, 45.42</b>	0.42	0.07, 2.42
150 to 179 min	0.32	0.05, 2.31	5.00	0.68, 36.79	0.63	0.09, 4.38
180 to 209 min	0.23	0.04, 1.38	4.32	0.61, 30.70	0.89	0.15, 5.18
≥ 210 min	<b>0.09*</b>	<b>0.01, 0.69</b>	4.92	0.57, 42.24	0.16	0.01, 2.08
<b>Control variables</b>						
Widowed	0.20*	0.05, 0.83	0.26	0.04, 1.55	1.42	0.26, 7.74
Older age (years)	0.96	0.87, 1.05	1.06	0.96, 1.17	0.88*	0.78, 1.00
Household income	1.54	0.90, 2.63	1.68	0.95, 2.95	0.99	0.52, 1.86
Residence years	0.98	0.94, 1.01	0.96	0.92, 1.00	1.01	0.96, 1.05
Physical function	0.99	0.65, 1.53	0.80	0.55, 1.17	0.73	0.47, 1.14
SF-12 PCS <sup>1</sup>	1.00	0.97, 1.03	0.97	0.94, 1.00	1.01	0.98, 1.05
SF-12 MCS <sup>2</sup>	0.98	0.94, 1.02	1.04	1.00, 1.10	1.00	0.95, 1.04
<b>MVPA (ref: &lt; 10 min)</b>						
10 to 19 min	0.14	0.02, 1.07	6.28	0.82, 48.32	0.89	0.08, 10.09
20 to 29 min	0.31	0.03, 3.85	5.18	0.51, 52.90	3.99	0.35, 45.53
30 to 39 min	0.21	0.02, 1.88	4.08	0.45, 36.62	1.00	
40 to 49 min	<b>0.10*</b>	<b>0.01, 0.93</b>	1.32	0.11, 15.50	0.35	0.03, 4.36
≥ 50 min	0.15	0.02, 1.35	3.40	0.40, 29.16	0.31	0.03, 3.65
<b>Control variables</b>						
Widowed	0.35	0.09, 1.30	0.32	0.06, 1.72	1.46	0.26, 8.31
Older age (years)	0.95	0.86, 1.06	1.01	0.91, 1.12	0.85*	0.73, 0.99
Household income	1.66	0.99, 2.80	1.36	0.81, 2.29	0.94	0.48, 1.84
Residence years	0.99	0.95, 1.03	0.96	0.92, 1.00	1.00	0.95, 1.04
Physical function	1.22	0.75, 1.99	0.68	0.43, 1.07	0.70	0.41, 1.20
SF-12 PCS	1.00	0.97, 1.03	0.98	0.95, 1.01	1.02	0.98, 1.06
SF-12 MCS	0.98	0.94, 1.02	1.05*	1.00, 1.10	1.00	0.95, 1.05
<b>TPA (ref: &lt; 120 min)</b>						
120 to 149 min	0.92	0.06, 13.29	<b>12.92*</b>	<b>1.03, 162.17</b>	0.53	0.05, 6.16



150 to 179 min	0.28	0.02, 3.70	<b>258.64**</b>	<b>7.77, 9.E+03</b>	0.87	0.04, 19.14
180 to 209 min	0.12	0.01, 1.11	<b>23.66*</b>	<b>1.72, 324.59</b>	0.85	0.09, 7.57
210 to 239 min	0.14	0.01, 1.55	9.08	0.61, 134.49	0.41	0.04, 3.98
240 to 269 min	0.21	0.02, 2.88	<b>19.46*</b>	<b>1.14, 333.52</b>	0.22	0.01, 4.05
≥ 270 min	<b>0.05*</b>	<b>0.00, 0.66</b>	9.20	0.60, 140.70	0.14	0.01, 1.89
<b>Control variables</b>						
Widowed	0.16*	0.03, 0.75	0.17	0.02, 1.26	1.42	0.25, 8.13
Older age (years)	0.94	0.84, 1.04	1.02	0.92, 1.14	0.85*	0.74, 0.98
Household income	1.46	0.84, 2.52	2.00*	1.07, 3.75	0.94	0.49, 1.81
Residence years	0.98	0.94, 1.02	0.95*	0.91, 1.00	1.00	0.96, 1.05
Physical function	1.00	0.64, 1.56	0.64	0.41, 1.02	0.70	0.44, 1.11
SF-12 PCS	1.01	0.98, 1.04	0.96*	0.93, 1.00	1.02	0.98, 1.06
SF-12 MCS	0.97	0.93, 1.02	1.06*	1.00, 1.12	0.99	0.95, 1.04

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\* p<0.05, \*\* p<0.01 (shown in bold for independent variable). <sup>1</sup> Physical component score, <sup>2</sup> Mental Component Score. Note: Odds Ratio's under 1.00 indicate that the likelihood of social isolation is lower for that given response category, compared with the reference category. Odds Ratio's over 1.00 indicate that the likelihood of social isolation is higher for that given response category, compared with the reference category.



Supplementary Figure 1. Map of most deprived Lower Super Output Areas in the West of England CRN area in Wiltshire.

## Supplementary File 1. Thematic analysis

Table 1. Lower and higher-level categories of activity types derived from the 7-day diary entries

No.	Higher-level activity categories (Used in OPAL: Fox et al., 2011)	Lower-level activity categories observed inductively from 7-day activity diaries (Fitted under the higher-level categories used in OPAL, or in new ones if necessary)
1	Shopping	1. [32] General shopping [general - mostly food shopping at larger stores] 2. [33] Local shopping [to local or village shop for the daily paper or other] 3. [38] DIY shopping
2	Visits / social events  [Includes meeting people in a non-home setting]	1. [2] Visiting young family [visit to children and or grandchildren's home or out] 2. [3] Visiting siblings [visit siblings (or in law), their home or out] 3. [4] Visiting parents [parent visit or help or visiting parents grave] 4. [5] Visiting spouse [visit spouse in caring facility] 5. [6] Group social [parties or social events, village activities, social groups] 6. [8] Coffee, tea-related social meetings [coffee or tea and cakes out with friends] 7. [9] Funerals [acquaintances' funerals] 8. [10] Social visits [to friends' homes] 9. [11] Shopping-related social meetings [meet friends for or during shopping] 10. [12] Neighbourly social [practical or chance neighbourly interaction]
3	Entertainment	1. [7] Food-related social [lunch or dinner with friends] 2. [54] Musical or theatrical entertainment [bands, concerts, theatre shows, cinema, street parade] 3. [56] Spectating sport 4. [58] Eating or drinking out
4	Personal / household errands	1. [34] Post-related errands 2. [35] Car-related errands 3. [36] Bank or accountant errands 4. [37] Library errands

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		<ul style="list-style-type: none"> <li>5. [39] Recycling errands [to the waste tip or recycling services]</li> <li>6. [40] Pet errands [pet shopping or to vets]</li> <li>7. [55] Beauty or grooming treatment</li> </ul>
5	Escort	<ul style="list-style-type: none"> <li>1. [1] Caring for grandchildren [child-minding in grandchildren's home or escorting children between destinations]</li> <li>2. [14] Inter-personal help [inter-personal practical help or caring - not including caring for grandchildren]</li> <li>3. [15] Transport help [giving others car lifts, excluding grandchildren]</li> </ul>
6	Sports / exercise	<ul style="list-style-type: none"> <li>1. [19] Structured exercise [gym, studio or pool-based exercise or movement; group or individual] <i>(pool-based exercise included in frequency variable, but not in objective PA variables)</i></li> <li>2. [20] Bike ride [for exercise reasons]</li> <li>3. [21] Outdoor running [for exercise reasons]</li> <li>4. [22] Golf</li> <li>5. [23] Tennis</li> <li>6. [49] Social physical games [bowling, bowls or skittles]</li> </ul>
7	Health	<ul style="list-style-type: none"> <li>1. [44] Hospital or GP appointments</li> <li>2. [45] Non-GP medical appointments [Dentist, Podiatrist, Chiropodist, Physiotherapy or Homeopath appointments or Chemist]</li> </ul>
8	Day trip	<ul style="list-style-type: none"> <li>1. [53] Nature and heritage outings [nature, countryside house, museum or city-focussed outings]</li> <li>2. [57] Holidays</li> </ul>
9	Hobby	<ul style="list-style-type: none"> <li>1. [42] Horse care tasks</li> <li>2. [47] Musical hobby [in a band or choir]</li> <li>3. [48] Social games [bingo or bridge in local social centres]</li> <li>4. [50] Hobby in nature [birdwatching, picking blackberries, fly-fishing, shooting]</li> <li>5. [51] Interest group activities [book club, gardening club, gliding club [NADFAS society, pub quizzes, continuing education clubs]</li> </ul>

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		6. [52] Artistic hobby [sketching, painting, pottery or sewing]
10	Religion	1. [46] Church-related activities
<b>Additional categories (not in Davis et al., 2011)</b>		
11	Walking for leisure or exercise	1. [18] Walking for exercise
12	Dog walking	2. [41] Dog walking
13	Volunteering	1. [13] Committee meetings 2. [16] Volunteering in community [community-benefitting volunteering or help (village shop, maintaining public property and green spaces, running clubs, events or Speed Watch)] 3. [17] Volunteering outside community [formal charity work outside community]
14	Paid work	1. [59] Farm work 2. [60] Manual work from home, non-farming 3. [61] Office work from home 4. [62] Work needing travel
15	Gardening	1. [24] Allotment work [away from home] 2. [25] Gardening [Garden maintenance work (in garden or greenhouse)]
		[While in OPAL they did not include gardening in one's own garden in this category, I think we need to here as having just the 'allotment work' will not generate enough responses. Many people gardened at home, but few people had an allotment.]
16	Activities around the house (non-gardening)	1. [26] Non-garden work in garden [cleaning things, emptying kitchen waste, hanging laundry, feeding fish, chicken birds and bees] 2. [27] Working with wood [moving and working with fire wood] 3. [28] DIY [work in shed, garage, workshop and front drive] 4. [29] Car maintenance work 5. [30] Front drive tasks [loading and unloading from car, emptying dustbins]