

1 **Is Physical Activity Associated With Loneliness or Social Isolation In Older**  
2 **Adults? Results of a longitudinal analysis using the TILDA Study.**

3

Ilona I. McMullan, (1), Brendan P. Bunting, Annette Burns (2), Lee Smith (3), Connor Cunningham (2), Roger O'Sullivan (2), Nicole E. Blackburn (1), Jason J. Wilson (1), Mark A. Tully (1)

1 Institute of Mental Health Sciences, School of Health Sciences, Ulster University, Newtownabbey, United Kingdom. Email: [i.mcmullan@ulster.ac.uk](mailto:i.mcmullan@ulster.ac.uk); [m.tully@ulster.ac.uk](mailto:m.tully@ulster.ac.uk), [bp.bunting@ulster.ac.uk](mailto:bp.bunting@ulster.ac.uk); [ne.blackburn@ulster.ac.uk](mailto:ne.blackburn@ulster.ac.uk); [jj.wilson@ulster.ac.uk](mailto:jj.wilson@ulster.ac.uk)

2. Institute of Public Health in Ireland, Belfast/Dublin. Email: [conor.cunningham@publichealth.ie](mailto:conor.cunningham@publichealth.ie); [annette.burns@publichealth.ie](mailto:annette.burns@publichealth.ie); [roger.osullivan@publichealth.ie](mailto:roger.osullivan@publichealth.ie)

3. Cambridge Centre for Sport and Exercise Sciences, Anglia Ruskin University, Compass House, Cambridge, CB1 1PT. [Lee.smith@anglian.ac.uk](mailto:Lee.smith@anglian.ac.uk)

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

21

22

23

24

25

26

27

28

29

30

**31 Abstract**

32 Social relationships are central to the health and well-being of older adults. Evidence exploring the  
33 association of physical activity (PA) with social isolation and loneliness is limited. This study uses a  
34 path analysis to investigate the longitudinal association between loneliness and social isolation with  
35 PA using the Irish Longitudinal study of Ageing (TILDA). Higher levels of social isolation measured  
36 using the Berkman-Syme Social Network Index (SNI) were directly and indirectly associated with  
37 lower levels of walking, moderate PA (MPA) and vigorous PA (VPA) over six years. Additionally,  
38 higher levels of walking were associated with lower levels of loneliness measured using a modified  
39 version of the University of California Los Angeles loneliness scale (UCLA) over a 3-year period.  
40 Future interventions should target individuals who are more socially isolated and explore the effects  
41 of different types of PA on loneliness over time.

**42 Key words**

43 physical activity; social isolation; loneliness; older adults

44

45

46

47

48

49

50

51

52

**53 Introduction**

54 Loneliness is a subjective experience which describes the lack of meaningful connections and  
55 relationships. It is the subjective difference between an individual's preferred and actual situation,  
56 where as social isolation is an objective measurement of the number of relations, social interactions,  
57 social support structures, engagements and activities (Fried et al., 2020; Shvedko et al., 2018; Steptoe  
58 et al., 2013; Weis, 1975). Importantly, both concepts are related, but the two do not always correlate  
59 and individuals may feel lonely despite having many social contacts, while others may not experience  
60 loneliness despite having few social contacts (McHugh et al., 2017; Perlman & Peplau, 1981).  
61 Furthermore, many factors such as individual characteristics, cultural factors, and the social  
62 environment can influence both loneliness and social isolation (Schrempft et al., 2019; Shvedko et al.,  
63 2018).

64 Loneliness and social isolation are not an inevitable part of growing older, and data from the UK over  
65 the last number of decades indicates that chronic loneliness is present in just 8-9% of older adults  
66 (65+) (Victor et al. 2002) while 34% of those aged 52 and over in England reported they are  
67 'sometimes'(25%) or 'often'(9%) lonely in 2009-2010 based on data from the English Longitudinal  
68 Study on Ageing (Beaumont, 2013). Older adults may be more at risk of loneliness or social isolation  
69 due to increased difficulty in maintaining social participation following a decrease in mobility or health,  
70 increased poverty, as well as a loss of social resources through bereavement (Aartsen & Jylhä,  
71 2011;.Bukov et al., 2002; Desrosiers et al., 2004; Glass et al., 2006; Griffin, 2010; Levasseur et al., 2011;  
72 Maier & Klumb, 2005; Nicholson, 2012; Victor, 2011). Loneliness in older adults is particularly  
73 concerning due to the wide range of associated negative health consequences (Pels & Kleinert, 2016).  
74 Research suggests that either through psychobiological or behavioural pathways, loneliness increases  
75 the risk of chronic disease (Lauder et al., 2006; Senez et al., 2004; Shankar et al., 2011; Thurston &  
76 Kubzanskv, 2009); cognitive impairment (Pitkala et al., 2011); and all-cause mortality (Elovanio et al.,  
77 2017; Patterson & Veensta, 2010; Newall et al., 2013). A more recent umbrella review of observational  
78 studies (795 studies, and 746,706 participants) suggests an association between loneliness and

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

79 dementia (relative risk, RR=1.26; 95%CI: 1.14-1.40, I2 23.6%), paranoia (odds ratio, OR=3.36; 95%CI:  
80 2.51-4.49, I2 92.8%) and psychotic symptoms (OR=2.33; 95%CI: 1.68-3.22, I2 56.5%) (Solmi et al.,  
81 2020). It is estimated that the social and healthcare benefits of addressing loneliness in the UK are  
82 approximately £900 per person per annum (Bernard, 2013). Consequently, there is a need to  
83 understand how this growing public health concern might be addressed.

84 The health benefits of physical activity (PA) in older adults are well established (Bangsbo et al., 2019;  
85 Cunningham et al., 2020; Silverman & Duester, 2014; Fried et al; 2020), and loneliness reduction  
86 models suggest that PA may also have an important role for loneliness through social, psychological,  
87 and biological mechanisms (Shvedko et al., 2018). For example, Social Compensation Effect theory  
88 suggests that PA increases social participation through group activities which can compensate for the  
89 loss of meaningful social relationships, provide opportunities to develop relationships, and facilitate  
90 an individual's perception of social support (Ferraro & Farmer, 1995, Sheridan et al., 2014); the  
91 Broaden and Build Theory of Positive Emotions theory suggests that PA generates positive emotions  
92 and feelings of well-being which removes the barriers to social interaction and consequently reduces  
93 loneliness (Cohen & Wills, 1985; Fredrickson, 1998; Milligan et al., 2013; Newhall et. al., 2013); and  
94 the Tripartite Model of Group Identification suggests that through cognitive, affective, and behaviour  
95 a sense of identification and social attraction to group members with shared interests and goals can  
96 develop during PA which decreases loneliness (Hawkey et al., 2009; Henry et al., 1999).

97 Whilst emerging, studies exploring the association between PA and loneliness in older adults are  
98 limited. More specifically, Shvedko et al.'s (2018) systematic review (n= 38 studies; 5288 participants)  
99 suggests that there is a lack of evidence regarding the effectiveness of PA interventions with only one  
100 study (n = 294 participants; mean age=23.6 years) supporting the efficacy of the tripartite model  
101 successfully decreasing loneliness in the context of PA interventions. Additionally, studies exploring  
102 the longitudinal association between PA and loneliness are lacking (Fried et al., 2020; Tully et al., 2019;  
103 Victor & Bowling, 2011). For example, Pels et al.'s (2016) systematic review (n=37 studies) exploring

## PHYSICAL ACTIVITY, LONELINESS & SOCIAL ISOLATION

104 the association between PA and loneliness found that PA can contribute to a decrease in loneliness  
105 and that loneliness itself might reduce the probability of being physically active. However, most  
106 studies included were cross-sectional (24 studies), with only seven longitudinal studies of which only  
107 three explored the effect of PA on loneliness. Also, previous studies have highlighted the dynamic  
108 nature of loneliness experienced by older adults, and so establishing the factors linked to loneliness  
109 within a life course or longitudinal perspective is important to better inform the design of more  
110 effective interventions in a rapidly ageing society (Solmi et al., 2020; Victor et al., 2009).

111 This study aims to bring new insights to the understanding of the association between PA and  
112 loneliness in older adults using secondary data analysis of longitudinal data from the Irish Longitudinal  
113 study of Ageing (TILDA). The questions addressed were: (1) what changes occur in PA, loneliness, and  
114 social isolation over time in older adults? and (2) what is the relationship between PA, loneliness and  
115 social isolation over time in older adults?

116

## 117 **Method**

### 118 **Participants**

119 TILDA is an ongoing cohort study of ageing that includes community-dwelling older adults ( $\geq 50$  years)  
120 in the Republic of Ireland (Kearney, Cronin and O'Regan, 2011). In brief, the sampling frame used in  
121 TILDA was the Irish Geodirectory, a listing of residential addresses from which a clustered sample of  
122 addresses was chosen and stratified according to area, level of socioeconomic status, and  
123 geographical location. Addresses were selected within each geographic cluster, and all household  
124 residents  $\geq 50$  years along with their spouses/partners were eligible to participate (Kearney et al.,  
125 2011). Data collection included a computer-assisted personal interview (CAPI); a self-completed  
126 questionnaire; and a health assessment. This study uses data from wave 1 (2009-11), wave 2 (2012-  
127 13), and wave 3 (2014-15). In total, the household response rate was 62% (8504 participants) for wave  
128 one, 86% (7455 participants) for wave two, and 62% (6279 participants) for wave three.

## PHYSICAL ACTIVITY, LONELINESS & SOCIAL ISOLATION

129 The data were provided free of charge through an online application process for the purposes of this  
130 analysis by the Irish Social Science Data Archive (ISSDA) at University College Dublin  
131 (<http://www.ucd.ie/issda/data/tilda/>) and the Interuniversity Consortium for Political and Social  
132 Research (ICPSR) at the University of Michigan  
133 (<http://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/34315>). Ethical approval for TILDA was  
134 obtained from the Trinity College Dublin Research Ethics

### 135 **Assessment of Physical Activity (PA)**

136 PA was assessed using the International Physical Activity Questionnaire (IPAQ) (short form), a self-  
137 reported measure of time spent over the last 7 days on different PA levels (reliability: 0.89; validity:  
138 0.80; Craig et al., 2003; Hallal et al., 2012). From the IPAQ we included the total minutes of vigorous  
139 physical activity (VPA) like heavy lifting, digging, aerobics, or fast bicycling; moderate physical activity  
140 (MPA) like carrying light loads, bicycling at a regular pace, or doubles tennis; and walking activity at  
141 work and home, travelling from place to place, and walking for recreation, sport, exercise, or leisure  
142 completed over a week (total mins per week).

### 143 **Assessment of loneliness, social isolation, and social asymmetry**

#### 144 *Loneliness*

145 The Office for National Statistics (ONS) recommend the use of both direct and indirect measures to  
146 assess loneliness, and refer to the University of California-Los Angeles (UCLA) Loneliness scale (Russell,  
147 1996) (UCLA) as a direct measure, and the single question 'How often do you feel lonely?' as a  
148 subjective measure (Snape & Martin, ONS, 2018). Both measures are available from TILDA and are  
149 used in this analysis.

150 Previous research suggests that the (20 item long-form) has a high internal consistency (coefficient  $\alpha$   
151 ranging from 0.89 to 0.94) and test-retest reliability over a 1-year period ( $r = 0.73$ ) (Russell, 1996). A  
152 short form version of the UCLA (UCLA-6) was also found to have a good test-retest reliability ( $r=0.66$ )  
153 (Xu et al., 2018). The direct measure included in this analysis is the modified version of the UCLA which

## PHYSICAL ACTIVITY, LONELINESS & SOCIAL ISOLATION

154 assesses loneliness using five questions: How often do you feel left out?; How often do you feel  
155 isolated; How often do you feel in tune with the people around you?; How often do you feel you lack  
156 companionship?; and How often do you feel lonely? (often, some of the time, hardly ever). Higher  
157 scores indicate greater loneliness (score range 1-10).

158 The indirect measure employs item-5 of the modified UCLA a self-reported question: How often do  
159 you feel lonely? (rarely or never, some of the time, moderate amount of the time, and all the time).  
160 Higher scores indicate greater loneliness (score range 1-4).

### 161 *Social isolation*

162 TILDA uses the size of participants' social network to measure social isolation using the Berkman-Syme  
163 Social Network Index (SNI) (Cohen et al., 1997). SNI is a composite measure of four types of social  
164 connection: marital status (married versus not); sociability (number and frequency of contact with  
165 children, close relatives, and close friends); church group membership; and membership in other  
166 community organisations. The SNI is a well-validated scale for measuring social networks and has been  
167 used to predict both short- and long-term mortality (Berkman & Syme, 1979; House et al., 1982). This  
168 index is scored on a 0-4 composite scale and higher scores indicate less social isolation.

### 169 *Social asymmetry*

170 To address the discrepancy between desired and actual social networks where someone may feel  
171 lonely whilst having a large social network, or not feel lonely despite having a lack of social network  
172 (McHugh et al., 2017), the UCLA and SNI measures (as described above) have been combined in a  
173 measure of social asymmetry. Social asymmetry is introduced as an interaction within the model such  
174 that the outcome variable of PA is affected by an individual's score on social isolation, but that effect  
175 also depends on the individual's score on UCLA.

### 176 **Covariates**

177 Research suggests that socio-demographic covariates of age (years), sex (male/female), marital status  
178 (single, married, widowed, divorced), employment status (yes/no), and education (primary,

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

179 secondary, higher) play an important role in loneliness (Schrempft et al., 2019; Shvedko et al., 2018).  
180 Additionally, general health status measured using a self-reported question (how is your health?  
181 excellent/very good/good/fair/poor), and cognitive health (orientation, comprehension, attention,  
182 recall, and language skills) measured using the Mini Mental State Exam (MMSE; Folstein et al., 1975)  
183 were also included in the analysis (Schrempft et al., 2019; Shvedko et al., 2018).

184 Evidence also highlights the beneficial impact of social participation on health and wellbeing in older  
185 adults ( $\geq 60$  years) and so the summed total of 15 questions relating to structured activities (e.g.  
186 attending classes, participating in sport activities or exercise, and undertaking voluntary activities  
187 were asked); unstructured activities (e.g. such as visiting people, reading a book, watching television,  
188 listening to music or the radio, going to see a play, eating out, working in the garden, carrying out  
189 hobbies, playing cards/games, and going to the pub; and a question on voting participation: yes/no)  
190 was included (Aartsen & Jylhä. 2011; Levasseur et al., 2011, Maier & Klumb, 2005).

**191 Statistical analysis**

192 Characteristics of the study population were summarised using descriptive statistics (Table 1).

193 A cross lagged path model was used to investigate the longitudinal associations between loneliness  
194 (UCLA, self-rated loneliness, and social isolation) and PA (IPAQ: walking, MPA, and VPA) over three  
195 waves of data (across six years) adjusted for prespecified covariates based on existing literature,  
196 (Alwin, 2007) (Figure 1). An interaction effect of social asymmetry was introduced into the model to  
197 explain PA.

198 Model fit was evaluated using a Root Mean Square Error of Approximation (RMSEA)  $\leq 0.05$  with an  
199 upper limit (90% CI)  $\leq 0.08$ ; a Comparative Fit Index (CFI)  $\geq 0.95$ ; and a Standardised Root Mean Square  
200 Residual (SRMR)  $\leq 0.08$  (Hoyle, 1995). Where the levels of fit indices were not achieved, the  
201 modification indices were examined, and where appropriate, adjustments were made. Statistical  
202 significance was set at  $p < 0.05$ . A high estimate (Est) indicates a strong effect/relationship, whilst a low

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

203 estimate indicates a weaker effect/relationship. All analyses were conducted in Mplus (version 7.4;  
204 Muthen & Muthen, Los Angeles, CA).

205 Maximum likelihood estimation with robust standard errors (MLR) was used and is robust to non-  
206 normality (Enders, 2013; Yaun & Bentler, 2000). Missing data were assumed to be missing at random  
207 where systematic differences between the missing and observed values are assumed to be explained  
208 by other observed variables (Schafer & Graham, 2002). MLR utilises a model-based strategy for dealing  
209 with missing data which enables all participants to be included in analysis.

210

## 211 **Results**

212 In brief, the sample analysed in this study consisted of 8,504 participants with a mean age of 63  
213 (SD=9.41) years. 56% were female; 70% were married; 70% had a secondary education or above; and  
214 95% experienced good-to-excellent health.

215 81% of the sample reported that they rarely felt lonely, and mean scores for loneliness (UCLA: mean,  
216 SD: wave 1 1.92, 2.19; wave 2 1.92, 2.19; wave 3 1.69, 2.07), and social isolation (mean, SD: wave 1  
217 2.86, 0.88; wave 3 2.79, 0.91) indicated that the sample had low levels of loneliness and isolation. 52%  
218 of participants indicated that they did not participate in social activities. The model described the data  
219 well where fit statistics showed Root Mean Square Error of Approximation  $\leq 0.05$  (RMSEA=0.04) (with  
220 an upper limit  $\leq 0.08$  (90% CI=0.03, 0.04); a Comparative Fit Index  $\geq 0.95$  (CFI=0.98); and a Standardised  
221 Root Mean Square Residual  $\leq 0.08$  (SRMR=0.03) (Hoyle, 1995).

222 The results from the path analysis are summarised in Table 2 and are described below.

### 223 **Direct effects**

#### 224 *Physical activity (Wave 1, 2, and 3)*

225 Table 2 shows that PA (VPA, MPA, or walking) did not have any statistically significant effect on the  
226 measures of loneliness (UCLA, self-rated loneliness) or social isolation excluding an effect between

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

227 walking at wave two and UCLA at wave 3 (Est=-0.05; SE=0.02) where higher levels of walking  
 228 reduced feelings of loneliness.

229 VPA at wave one had a statistically significant direct effect on VPA at wave two (Estimate (Est)=0.05;  
 230 Standard error (SE)=0.01), and VPA at wave two had a statistically significant direct effect on VPA at  
 231 wave three (Est=0.12; SE=0.02). MPA at wave one did not have a statistically significant direct effect  
 232 on MPA at wave two (Est=0.02; SE=0.01), but MPA at wave two had a statistically significant direct  
 233 effect on MPA at wave three (Est=0.11; SE=0.02). Similarly, walking at wave one did not have a  
 234 statistically significant direct effect on walking at wave two (Est=0.01; SE=0.01), but walking at wave  
 235 two had a statistically significant direct effect on walking at wave three (Est=0.10; SE=0.02).

236 *UCLA, self-rated loneliness, and social isolation (Wave 1, 2, and 3)*

237 Table 2 shows that UCLA at wave one had a statistically significant direct effect on UCLA at wave two  
 238 (Est=0.91; SE=0.04), and UCLA at wave two had a statistically significant direct effect on UCLA at  
 239 wave three (Est=0.91; SE=0.02). Self-reported loneliness at wave one had a statistically significant  
 240 direct effect on self-reported loneliness at wave two (Est=0.82; SE=0.06), and self-reported  
 241 loneliness at wave two had a statistically significant direct effect on self-reported loneliness at wave  
 242 three (Est=0.81; SE=0.05). Similarly, social isolation at wave one had a statistically significant direct  
 243 effect on social isolation at wave three (Est=0.86; SE=0.02).

244 There were no statistically significant direct effects of the measures of UCLA or self-rated loneliness  
 245 on any measure of PA (VPA, MPA, walking). However, social isolation at wave 1 had a statistically  
 246 significant direct effect on VPA at wave two (Est=0.05; SE=0.02), and wave three (Est=0.07; SE=0.03);  
 247 MPA at wave two (Est=0.05; SE=0.02); and walking at wave three (Est=0.07; SE=0.03).

248 There were no statistically significant direct effects of social asymmetry on VPA, MPA or walking.

249 ***Total effects (indirect and direct)***

250 *Loneliness and Physical activity*

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

251 Table 3 shows that there were no statistically significant total effects between the UCLA loneliness  
252 score, self-rated loneliness, or social asymmetry and VPA, MPA, or walking over time.

253 A statistically significant total effect between social isolation at wave one and VPA, MPA, and  
254 walking at wave three was shown suggesting that social isolation has a cumulative effect on PA level  
255 over time via its effect on social isolation and PA. For example, a statistically significant total  
256 relationship between social isolation at wave one and VPA at wave three (Est=0.12; SE=0.02) was  
257 shown via the indirect effect of VPA at wave two (Figure 1: path G+B), social isolation at wave 3  
258 (Figure 1: path C+H), VPA at wave two and social isolation at wave three (Figure 1: path G+F+I), MPA  
259 at wave two and social isolation at wave three (Figure 1: path G+F+I), walking at wave two and social  
260 isolation at wave three (Figure 1: path G+F+I), and the direct effect between social isolation at wave  
261 one and VPA at wave three (Figure 1: path J).

262 A statistically significant total effect between social isolation at wave one and MPA at wave three  
263 (Est=0.14; SE=0.02) was also shown via the indirect effect of MPA at wave two (Figure 1: path G+B),  
264 social isolation at wave 3 (Figure 1: path C+H), VPA at wave two and social isolation at wave three  
265 (Figure 1: path G+F+I), MPA at wave two and social isolation at wave three (Figure 1: path G+F+I),  
266 walking at wave two and social isolation at wave three (Figure 1: path G+F+I), and the direct effect  
267 between social isolation at wave one and MPA at wave three (Figure 1: path J).

268 Additionally, a statistically significant total relationship between social isolation at wave one and  
269 walking at wave three (Est=0.06; Est=0.02) was shown via the indirect effect of walking at wave two  
270 (Figure 1: path G+B), social isolation at wave 3 (Figure 1: path C+H), VPA at wave two and social  
271 isolation at wave three (Figure 1: path G+F+I), MPA at wave two and social isolation at wave three  
272 (Figure 1: path G+F+I), walking at wave two and social isolation at wave three (Figure 1: path G+F+I),  
273 and the direct effect between social isolation at wave one and walking at wave three (Figure 1: path  
274 J).

## PHYSICAL ACTIVITY, LONELINESS & SOCIAL ISOLATION

275 The results also showed that age (VPA: Est=-0.01; SE=0.01; MPA: Est=-0.08; SE=0.02; walking: Est=-  
 276 0.07; SE=0.01), sex (VPA: Est=-2.06; SE=0.20; MPA: Est=-1.52; SE=0.25; walking: Est=-0.44; SE=0.18)  
 277 and health status (VPA: Est=-0.63; SE=0.10; MPA: Est=-0.58; SE=0.12; walking: Est=-0.63; SE=0.09)  
 278 were statistically significant for all PA levels. Social participation was statistically significant for VPA  
 279 (Est=0.57; SE=0.15) and MPA (Est=0.89; SE=0.19) only. MMSE (Est=0.12; SE=0.05) and marital status  
 280 (Est=0.18; SE=0.09) were statistically significant for walking only.

281 Age (UCLA: Est=0.26; SE=0.05; social isolation: Est=0.01; SE=0.00); sex (self-rated loneliness:  
 282 Est=0.07; SE=0.03; social isolation: Est=0.10; SE=0.03); marital status (UCLA: Est=0.26; SE=0.05; self-  
 283 rated loneliness: Est=0.07; SE=0.01; social isolation: Est=-0.36; SE=0.02); health status (UCLA:  
 284 Est=0.36; SE=0.04; self-rated loneliness: Est=0.07; SE=0.01; social isolation: Est=0.36; SE=0.04); social  
 285 participation levels (UCLA: Est=-0.18; SE=0.09; social isolation: Est=0.58; SE=0.03); and MMSE score  
 286 (UCLA: Est=-0.11; SE=0.03; social isolation: Est=0.03; SE=0.01) were statistically significant for both  
 287 loneliness and social isolation. Employment status (UCLA: Est=0.13; SE=0.06) was statistically  
 288 significant for loneliness only.

## 289 Discussion

290 This is one of a few studies to investigate the association between PA and loneliness over time using  
 291 a large nationally representative sample of community-dwelling older adults. A path analysis was used  
 292 to investigate the hypothesis that PA mediates loneliness, or loneliness mediates PA controlling for  
 293 covariates of age; marital status; sex; physical and mental health; education; employment; and social  
 294 participation. Fit statistics indicated that the model described the data well.

## 295 Summary of findings

296 Loneliness and social isolation are related but different concepts (McHugh et al., 2017; Perlman &  
 297 Peplau, 1981), and distinguishing between the two concepts is important because it allows more  
 298 targeted interventions to be identified. For example, this analysis shows that higher levels of social  
 299 isolation, not loneliness were directly associated with lower levels of walking over six years, MPA over  
 300 three years and VPA over three and six years. Social isolation also had a total effect on walking, MPA,

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

301 and VPA via its effect on PA and social isolation over six years. Additionally, higher levels of walking  
302 were associated with lower levels of loneliness based on a modified version of the UCLA scale over a  
303 3-year period.

304 National PA guidelines encourage increased levels of PA for mental health benefits such as decreased  
305 depression and loneliness (Care DoHas, 2019), and the results from this study support this, with the  
306 finding that increased levels of walking may reduce feelings of loneliness in older community-dwelling  
307 adults, over a 3-year period. This finding is further supported by cross-sectional analyses (Shellito &  
308 Roldan, 2019: n=6,157 participants; Yu et al., 2017: n = 181 participants). Our study also found no  
309 association between MPA or VPA with the measures of loneliness or social isolation which is supported  
310 by a previous systematic review and meta-analysis of clinical trials exploring the effects of PA  
311 interventions on social isolation, loneliness and low social support in older adults (Schvedko et al.,  
312 2018: n= 38 studies; 5288 participants; 51–82 years), as well as a recent clinical trial exploring the  
313 effects of an exercise referral programme on PA and health of older adults (Tully et al., 2019: n=1360  
314 participants; mean age 75 years). However, whilst walking is considered a safe and popular form of  
315 increasing PA (Arnardottir et al., 2013; Department of Health 2011; Franco et al., 2015) consensus as  
316 to which types of PA contribute to the classifications of light (LPA), MPA or VPA is lacking. Walking for  
317 example, can be classed as either low, moderate, or vigorous and so there may be an overlap across  
318 classifications within studies (Milton et al., 2018). Future research should seek to understand the type  
319 of PA to more fully understand the effects of different intensities of walking in relation to loneliness.  
320 Additionally, it is not possible to identify whether the walking activity was carried out in a group setting  
321 and therefore it is not possible to establish whether this finding supports loneliness reduction theories  
322 in the context of PA. Consequently, further studies exploring walking within individual or group setting  
323 should be explored.

324 The results from this study showed that social isolation predicted lower levels of VPA, and MPA over  
325 a 3-year period and over the longer term of six years: VPA, MPA and walking. Social Compensation

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

326 effect model (Ferraro & Farmer, 1998) highlights the importance of social support in the context of  
327 the effectiveness of PA intervention for reducing loneliness (Shvedko et al., 2018). Socially isolated  
328 individuals have diminished self-regulation, an individual's capacity to change emotions or behaviour  
329 to meet the social norms exerted by their social contacts, which leads to a decreased motivation to  
330 participate in PA (Cacioppo et al., 2000, 2014; Ekkekakis & Petruzzello, 1999; Hawkey et al., 2007,  
331 2009; McAuley et al., 2007; Labouvie-Vief & Medler, 2002). Similarly, Schrempft et al.'s (2019) cross-  
332 sectional study among 267 participants (mean 66.01 years) found that time spent in light ( $\beta=-0.143$ ,  
333  $p=0.015$ ) and moderate to vigorous PA (MVPA) ( $\beta=-0.112$ ,  $p=0.051$ ) was less frequent in more isolated  
334 participants; and Kobayashi and Steptoe's (2018) 10-year longitudinal study among 3,392 older adults  
335 ( $\geq 52$  years) found that socially isolated participants were less likely to report weekly MVPA (RR = 0.86;  
336 0.77–0.97). Further research is needed to explore specific strategies that may be effective in  
337 supporting socially isolated individuals to increase PA.

338 However, a previous longitudinal analysis among 229 participants (50-68 years) found that loneliness  
339 predicted diminished odds of PA (OR = 0.61), and greater likelihood of transitioning from PA to  
340 inactivity (OR = 1.58) over three years (Hawkey et al., 2009). This study found that loneliness based  
341 on UCLA score or self-rated loneliness is not significantly associated with PA level. The differences in  
342 results may be due to the characteristics of our sample where 81% rarely felt lonely and 95% were in  
343 good health which may have biased the findings.

**344 Strengths and limitations**

345 Previous studies have highlighted the dynamic nature of loneliness and social isolation experienced  
346 by older adults, and so understanding the association between PA and both loneliness and social  
347 isolation within a life course perspective is important to better inform the design of more effective  
348 interventions in a rapidly aging society (Victor et al., 2009; Wenger & Burholt, 2004). Another key  
349 strength of this study is that it uses a quasi-simplex path analysis which simultaneously estimates both  
350 direct and indirect associations therefore enabling exploration of the reciprocal relationship between  
351 self-reported PA and measures of loneliness using longitudinal data over a 6-year period. Additionally,

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

352 this analysis addresses the discrepancy between desired and actual social networks by combining the  
353 measures of loneliness (UCLA) and social isolation to form a measure of social asymmetry (McHugh et  
354 al., 2017) and introducing this as an interaction within the model such that the outcome variable of  
355 PA is affected by an individual's score on social isolation, but that effect also depends on the  
356 individual's score on UCLA. This study is one of the first studies to explore social asymmetry and PA,  
357 and whilst finding no association, further investigation is warranted.

358 In terms of limitations however, the TILDA dataset has not been specifically designed to address the  
359 research question of this current study, but provides repeated measures of the same individuals and  
360 so is an opportunity to explore the research question in a less expensive and time intensive way than  
361 would be possible using a study design that includes prospective data collection (Smith et al., 2011).  
362 Additionally, the model assumes factorial invariance of the measures (Hays et al., 1994; Selig & Little,  
363 2012), and as this study includes only observed measures, it is not possible to test the assumption of  
364 factorial invariance. Consequently, the findings should be considered with caution and future research  
365 should consider including multiple measures to create a latent construct to address measurement  
366 error (Selig & Little, 2012). Additionally, the measures included in the analysis may give rise to bias.  
367 For example, the model includes repeated measures across time which may address factorial  
368 invariance but may give rise to a retest effect (Selig & Little, 2012). The measures are also subjective  
369 and may be influenced by health status, mood, depression, anxiety, or cognitive ability, as well as  
370 seasonal variation, social desirability, (Dyrstad et al., 2014; Murphy, 2009; Saelens et al., 2012).  
371 Furthermore, inaccuracy of self-reported PA may be more exaggerated among older adults because  
372 of recall error (Dyrstad et al., 2014; Murphy, 2009; Saelens et al., 2012). However, despite these  
373 concerns, self-reported PA has shown to have convergent validity with objective measures of PA in  
374 older adults (87–89 years) (Innerd et al., 2015).

375 This study also assumes that all the important predictors are included in the analysis, but there are  
376 many determinants of human behaviour which may potentially confound the results (Selig & Little,

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

377 2012) and as with any observational study we cannot rule out the potential for residual confounding.  
378 Future studies should, where possible, consider objective measures and additional predictors over  
379 time to address some of these biases (Bauman et al., 2009).

380 Another consideration is that previous research has been limited by difficulties in the recruitment of  
381 lonely older people (Dickens et al., 2011). This is evident from the characteristics of the sample  
382 included in this analysis where 81% of the sample rarely felt lonely, and mean scores for loneliness  
383 (UCLA: mean, SD: wave 1 1.93, 4.72; wave 2 1.92, 4.79; wave 3 1.69, 4.27), and social connectedness  
384 (mean, SD: wave 1 2.86, 0.77; wave 3 2.79, 0.83) indicated low levels of loneliness. Therefore, the  
385 sample characteristics may bias the findings.

386 Additionally, a limitation of this study is that the measure of PA used does not provide details of the  
387 context or type of PA carried out (e.g. individual versus group activities). Therefore, this study does  
388 not support loneliness reduction theories such as Social Compensation Effect theory (Ferraro &  
389 Farmer, 1995, Sheridan et al., 2014), the Broaden and Build Theory of Positive Emotions (Cohen &  
390 Wills, 1985; Fredrickson, 1998; Milligan et al., 2013; Newhall et al., 2013, or the Tripartite Model of  
391 Group Identification (Hawkey et al., 2009; Henry et al., 1999). Future research should seek to include  
392 more detailed measures of PA that include the context in which the PA was carried out.

393 Despite the limitations of this study, to the authors' knowledge, it is one of only a few to assess the  
394 association between PA and loneliness, social isolation and social asymmetry in a nationally  
395 representative sample of community-dwelling adults across time.

**396 Conclusion**

397 A key message from this study is that social isolation, and not loneliness, is associated with lower levels  
398 of PA (VPA, MPA, and walking) over time. This finding supports the importance of social support  
399 provided through PA participation and proposes that lack of social networks reduces both self-  
400 regulatory and social control processes that in turn reduce healthy behaviours such as PA. Future  
401 research should seek to add to the understanding of loneliness and social isolation within the context

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

402 of PA using an intervention study to explore a walking intervention for older adults and explore the  
403 effects of different setting (e.g. group versus individual) on loneliness and social isolation over time.

404

**References**

405 Aartsen, M., & Jylhä, M. (2011). Onset of loneliness in older adults: Results of a 28-year prospective  
406 study. *European Journal of Ageing*, 8(1), 31-8.

408 AgeUK. (2018). Campaign to end loneliness.org. Retrieved on May 27, 2019, from:

409 <https://www.campaigntoendloneliness.org/loneliness-research/>.

410 Alwin, D. F. (2007). *The margins of error: a study of reliability in survey measurement*. Wiley-

411 Blackwell. Hoboken, New Jersey. Downloaded on 30th March, 2020 from: [https://b-](https://b-ok.cc/book/492656/e588de)

412 [ok.cc/book/492656/e588de](https://b-ok.cc/book/492656/e588de).

413 Arnardottir, N.Y., Koster, A., Van Domelen, D.R., et al. (2013). Objective measurements of daily

414 physical activity patterns and sedentary behaviour in older adults: Age, Gene/Environment

415 Susceptibility-Reykjavik Study, *Age Ageing*, 42, 222–29.

416 Bangsbo, J., Blackwell, J., Boraxbeek, C., et al. (2019). Copenhagen Consensus statement 2019:

417 Physical activity and ageing. *British Journal of Sports Medicine*, Published Online First: 21

418 February 2019. Doi: 10.1136/bjsports-2018-100451.

419 Bauman, A., Ainsworth, B., Bull, F., et al. (2009). Progress and pitfalls in the use of the International

420 Physical Activity Questionnaire (IPAQ) for adult physical activity surveillance. *Journal of*

421 *Physical Activity and Health*, 6, S5–S8. PMID: 19998844.

422 Beaumont, J. (2012). Measuring national well-being - Older people and loneliness. Office of National

423 Statistics. Downloaded on 6<sup>th</sup> April 2020 from:

424 <https://webarchive.nationalarchives.gov.uk/20160106033529/http://www.ons.gov.uk/ons/r>

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 425 el/wellbeing/measuring-national-well-being/older-people-and-loneliness/art-measuring-  
426 national-well-being--older-people-and-loneliness.html
- 427 Berkman, L. F., & Syme, S. (1979). Social networks, host resistance, and mortality: A nine-year follow-  
428 up study of Alameda County residents. *American Journal of Epidemiology*, 109(2), 186-204.
- 429 Bernard, S. (2013). Loneliness and social isolation among older people in North Yorkshire, working  
430 paper (WP2565). *Social Policy Research Unit, University of York 2013*. Retrieved on April 30,  
431 2019 from <https://www.york.ac.uk/inst/spru/research/pdf/lonely.pdf>.
- 432 Bukov, A., Maas, I., & Lampert, T. (2002). Social participation in very old age: Cross-sectional and  
433 longitudinal findings from BASE. Berlin Aging Study. *Journal of Gerontology Series B*  
434 *Psychological Sciences and Social Science*, 57, 510–17.
- 435 Care DoHaS. (2019). UK Chief Medical Officers' Physical Activity Guidelines. London: Department of  
436 Health and Social Care; 2019.
- 437 Dickens, A.P., Richards, S.H., Hawton, A., et al. (2011). An evaluation of the effectiveness of a  
438 community mentoring service for socially isolated older people: A controlled trial. *BMC*  
439 *Public Health*, 11, 218. Doi: 10.1186/1471-2458-11-218.
- 440 Cacioppo, J.T., & Cacioppo, S. (2014). Social relationships and health: the toxic effects of perceived  
441 social isolation. *Social and Personality Psychology Compass*, 58–72. Retrieved on May 27,  
442 2019 from <https://doi.org/10.1111/spc3.12087>.
- 443 Cacioppo, J.T., Ernst, J.M., Burleson, M.H., et al. (2000). Lonely traits and concomitant physiological  
444 processes: The MacArthur social neuroscience studies. *International Journal of*  
445 *Psychophysiology*, 35, 143–54.
- 446 Cohen, S., Doyle, W. J., Skoner, D. P., et al. (1997). Social ties and susceptibility to the common cold.  
447 *Journal of the American Medical Association*, 277 (24), 1940–44.  
448 Doi:10.1001/jama.1997.03540480040036.

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 449 Cohen, S., & Wills, T.A. (1985). Stress, social support, and the buffering hypothesis. *Psychological*  
450 *Bulletin*, 98, 310-57. Retrieved on April 30, 2019 from [https://psycnet.apa.org/record/1986-](https://psycnet.apa.org/record/1986-01119-001)  
451 [01119-001](https://psycnet.apa.org/record/1986-01119-001).
- 452 Craig, C.L., Marshall, A.L., Sjöström, M., et al. (2003). International Physical Activity Questionnaire:  
453 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, 1381-95.
- 454 Cunningham, C., O' Sullivan, R., Caserotti, P., & Tully, M.A. (2020). Consequences of physical  
455 inactivity in older adults: A systematic review of reviews and meta-analyses. *Scandinavian*  
456 *Journal of Medicine & Science in Sports*, 30(5), 816-27. Doi: 10.1111/sms.13616.
- 457 Department of Health (DOH). (2011). UK physical activity guidelines. Retrieved on September 5,  
458 2019 from:  
459 [http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuid](http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_127931)  
460 [ance/DH\\_127931](http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_127931)
- 461 Desrosiers, J., Noreau, L., & Rochette, A. (2004). Social participation of older adults in Quebec. *Aging*  
462 *Clinical and Experimental Research*, 16, 406–12.
- 463 Dickens, A.P., Richards, S.H., Greaves, C.J., & Campbell, J.L. (2011). Interventions targeting social  
464 isolation in older people: a systematic review. *BMC Public Health*, 11, 647. Doi:  
465 <http://www.biomedcentral.com/1471-2458/11/647>.
- 466 Dyrstad, S.M., Hansen, D.M., Holme, I.M., & Anderssen, S.A. (2014). Comparison of self-reported  
467 versus accelerometer-measured physical activity. *Medicine & Science in Sports & Exercise*,  
468 46, 99-106.
- 469 Ekkekakis, P., & Petruzzello, S.J. (1999). Acute aerobic exercise and affect: Current status, problems,  
470 and prospects regarding dose-response. *Sports Medicine*, 28, 337-74.

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 471 Elovainio, M., Hakulinen, C., Pulkki-Råback, L., et al. (2017). Contribution of risk factors to excess  
 472 mortality in isolated and lonely individuals: an analysis of data from the UK biobank cohort  
 473 study. *Lancet Public Health*, 2, e260–66. Doi: 10.1016/S2468-2667(17)30075-0.
- 474 Enders, C.K. (2013). Dealing with missing data in developmental research. *Child Development*  
 475 *Perspectives*, 7, 27–31.
- 476 Ferraro, K.F., & Farmer, M.M. (1995). Social compensation in adulthood and later life. Compensating  
 477 for psychological deficits and declines: Managing losses and promoting gain. Chapter 6, 127–  
 478 45. Retrieved on April 30, 2019 from  
 479 [https://books.google.co.uk/books?hl=en&lr=&id=P8rIWdFqTuUC&oi=fnd&pg=PA127&dq=Ferraro+KF,+Farmer+MM.+Social+compensation+in+adulthood+and+later+life.+Compensating+for+Psychological+Deficits+and+Declines:+Managing+Losses+and+Promoting+Gain.+1995:127%E2%80%9345.&ots=YyEoQ50C-](https://books.google.co.uk/books?hl=en&lr=&id=P8rIWdFqTuUC&oi=fnd&pg=PA127&dq=Ferraro+KF,+Farmer+MM.+Social+compensation+in+adulthood+and+later+life.+Compensating+for+Psychological+Deficits+and+Declines:+Managing+Losses+and+Promoting+Gain.+1995:127%E2%80%9345.&ots=YyEoQ50C-P&sig=GeyPJwqsF2PQxxzJpJ51OSCfNNE&redir_esc=y#v=onepage&q&f=false)  
 480 [P&sig=GeyPJwqsF2PQxxzJpJ51OSCfNNE&redir\\_esc=y#v=onepage&q&f=false](https://books.google.co.uk/books?hl=en&lr=&id=P8rIWdFqTuUC&oi=fnd&pg=PA127&dq=Ferraro+KF,+Farmer+MM.+Social+compensation+in+adulthood+and+later+life.+Compensating+for+Psychological+Deficits+and+Declines:+Managing+Losses+and+Promoting+Gain.+1995:127%E2%80%9345.&ots=YyEoQ50C-P&sig=GeyPJwqsF2PQxxzJpJ51OSCfNNE&redir_esc=y#v=onepage&q&f=false)
- 484 Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975). "Mini-mental state". A practical method for  
 485 grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12(3),  
 486 189–98.
- 487 Franco, M.R., Tong, A., Howard, K., et al. (2015). Older people's perspectives on participation in  
 488 physical activity: a systematic review and thematic synthesis of qualitative literature. *British*  
 489 *Journal of Sports Medicine*, 1-9. Doi: 10.1136/bjsports-2014-094015.
- 490 Fredrickson, B. L. (1998). What good are positive emotions? *Review of General Psychology*, 2, 300–  
 491 19. Doi:10.1037/1089-2680.2.3.300.
- 492 Fried, L., Prohaska, T., Burholt, V., et al. (2020). A unified approach to loneliness. *Lancet*, 395  
 493 (10218), 114. Doi:10.1016/S0140-6736(19)32533-4.

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 494 Glass, T.A., De Leon, C.F.M., Bassuk, S.S., & Berkman, L.F. (2006). Social engagement and depressive  
495 symptoms in late life: longitudinal findings. *Journal of Aging and Health*, 18, 604–28.
- 496 Griffin, J. (2010). *The lonely society?* London: Mental Health Foundation.
- 497 Hallal, P.C., Andersen, L.B., Bull, F., et al. (2012). Global physical activity levels: surveillance, progress,  
498 pitfalls, and prospects. *The Lancet*, 380, 247-57.
- 499 Hawkey, L.C., Thisted, R.A., & Cacioppo, J.T. (2009). Loneliness predicts reduced physical activity:  
500 Cross-sectional & longitudinal analyses. *Health Psychology*, 28(3), 354–63.  
501 Doi:10.1037/a0014400.
- 502 Hawkey, L.C., & Cacioppo, J.T. (2007). Aging and loneliness: Downhill quickly? *Current Directions in*  
503 *Psychological Science*, 16, 187–91.
- 504 Hays, R.D., Marshall, G.N., Wang, E.Y.I., et al., (1994). Four-year cross-lagged associations between  
505 physical and mental health in the medical outcomes study. *Journal of Consulting and Clinical*  
506 *Psychology*, 62(3), 441–49.
- 507 Henry, K.B., Arrow, H., & Carini, B. (1999). A tripartite model of group identification theory and  
508 measurement. *Small Group Research*, 30, 558–81. Retrieved on April 30, 2019 from  
509 <https://doi.org/10.1177/104649649903000504>
- 510 House, J., Robbin, C., & Metzner, H. (1982). The association of social relationships and activities with  
511 mortality: Prospective evidence from the Tecumseh community health study. *American*  
512 *Journal of Epidemiology*, 116(1), 123-40.
- 513 Hoyle, R.H. (1995). *Structural Equation Modelling: Concepts, issues and applications*. Thousand Oaks,  
514 CA: Sage Publications, 1-132.

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 515 Innerd, P., Catt, M., Collerton, et al. (2015). A comparison of subjective and objective measures of  
516 physical activity from the Newcastle 85+ study. *Age and Ageing*, 44(4), 691–94.  
517 <https://doi.org/10.1093/ageing/afv062>
- 518 Kearney, P.M., Cronin, H., & O'Regan, C. (2011). Cohort profile: The Irish longitudinal study of ageing.  
519 *International Journal of Epidemiology*, 40, 877-84.
- 520 Kobayashi L.C., & Steptoe, A. (2018). Social isolation, loneliness, and health behaviors at older ages:  
521 longitudinal cohort study. *Annals of Behavioral Medicine*, 52, 582–93.
- 522 Labouvie-Vief, G., & Medler, M. (2002). Affect optimization and affect complexity: Modes and styles  
523 of regulation in adulthood. *Psychology and Aging*, 17, 571–88.
- 524 Lauder, W., Mummery, K., Jones, M., & Caperchione, C. (2006). A comparison of health behaviours in  
525 lonely and non-lonely populations. *Psychology Health & Medicine*, 11(2), 233-45.
- 526 Levasseur, M., Gauvin, L., Richard, L., et al. (2011). Associations between perceived proximity to  
527 neighborhood resources, disability, and social participation among community-dwelling  
528 older adults: Results from the VoisiNuAge study. *Archives of Physical Medicine and*  
529 *Rehabilitation*, 92(12), 1979-86.
- 530 Maier, H., & Klumb, P.L. (2005). Social participation and survival at older ages: is the effect driven by  
531 activity content or context? *European Journal of Ageing*, 2(1), 31-9.
- 532 Milligan, C., Dowrick, C., Payne, S., et al. (2013). Men's sheds and other gendered interventions for  
533 older men: improving health and wellbeing through social activity-A systematic review and  
534 scoping of the evidence base. Lancaster University Centre for Ageing Research: Lancaster.
- 535 Milton, K., Vareia, A.R., Strain, T., et al. (2018). A review of global surveillance on the muscle  
536 strengthening and balance elements of physical activity recommendations. *Journal of Frailty*  
537 *Sarcopenia and Falls*, 3 (2), 114-124. Doi: 10.22540/JFSF-03-114.

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 538 Murphy, S.L. (2009). Review of physical activity measurement using accelerometers in older adults:  
539 considerations for research design and conduct. *Preventive Medicine*, 48, 108–14.
- 540 McAuley, E., Morris, K.S., Motl, R.W., Hu, L., Konopack, J.F., & Elavsky, S. (2007). Long-term follow-up  
541 of physical activity behavior in older adults. *Health Psychology*, 26, 375–80.
- 542 McHugh, J.E., Kenny, R.A., Lawlor, B.A., Steptoe, A., & Kee, F. (2017). The discrepancy between social  
543 isolation and loneliness as a clinically meaningful metric: Findings from the Irish and English  
544 longitudinal studies of ageing (TILDA and ELSA). *International Journal of Geriatrics and*  
545 *Psychiatry*, 32(6), 664–74.
- 546 Newall, N.E., Chipperfield, J.G., Bailis, D.S., et al. (2013). Consequences of loneliness on physical  
547 activity and mortality in older adults and the power of positive emotions. *Health Psychology*,  
548 32, 921. Downloaded on April 30, 2019 from: <https://doi.org/10.1037/a0029413>.
- 549 Nicholson, N.R. (2012). A review of social isolation: An important but underassessed condition in  
550 older adults. *The Journal of Primary Prevention*, 33(2–3), 137–52.
- 551 Patterson, A.C., & Veenstra, G. (2010). Loneliness and risk of mortality: a longitudinal investigation in  
552 Alameda County, California. *Social Science & Medicine*, 71(1), 181-86.
- 553 Pels, F., & Kleinert, J. (2016). Loneliness and physical activity: A systematic review. *International*  
554 *Review of Sport and Exercise Psychology*, 9(1), 231-60. Doi:  
555 10.1080/1750984x.2016.1177849.
- 556 Perlman, D., & Peplau, L.A. (1981). Toward a social psychology of loneliness. In: Duck, S.W., Gilmour,  
557 R., editors. *Personal relationships in disorder*. London: Academic Press; 1981. p. 31–56.
- 558 Pitkala, K.H., Routasalo, P., Kautiainen, H., Sintonen, H., & Tilvis, R.S. (2011). Effects of socially  
559 stimulating group intervention on lonely, older people's cognition: a randomized, controlled  
560 trial. *American Journal of Geriatric Psychiatry*, 19(7), 654-63.

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 561 Russell, D. (1996). UCLA Loneliness Scale (Version 3): Reliability, validity, and factor structure. *Journal*  
562 *of Personality Assessment*, 66, 20-40.
- 563 Saelens, B.E., Sallis, J.F., Frank, L.D., et al. (2012). Neighborhood environmental and psychosocial  
564 correlates of adults' physical activity. *Medical Science of Sports Exercise*, 44, 637-46.
- 565 Schafer, J.L., & Graham, J.W. (2002). Missing data: our view of the state of the art. *Psychological*  
566 *Methods*, 7(2), 147-77.
- 567 Schrepft, S., Jackowska, M., Hamer, M., & Steptoe, A. (2019). Associations between social isolation,  
568 loneliness, and objective physical activity in older men and women. *BMC Public Health*,  
569 19(74). Doi: <https://dspace.lboro.ac.uk/2134/36669>.
- 570 Schvedko, A.V., Thompson, J.L., Greig, C.A., & Whittaker, A.C. (2018). Physical activity interventions  
571 for treatment of social isolation, loneliness or low social support in older adults: A systematic  
572 review and meta-analysis of randomised controlled trials. *Psychology of Sports Exercise*, 34,  
573 128-37.
- 574 Selig, J.P., & Little, T.D. (2012). Autoregressive and cross-lagged panel analysis for longitudinal data.  
575 Handbook of Developmental Research Methods. Chapter 16, Autoregressive and cross-lagged  
576 panel analysis for longitudinal data, Editors: B. Laursen, T. D. Little, N. A. Card, 265-78.
- 577 Senez, B., Felicioli, P., Moreau, A., & Le Goaziou, M.F. (2004). Quality of life assessment of type 2  
578 diabetic patients in general medicine. *Presse Medicale*, 33(3), 161-66.
- 579 Shankar, A., McMunn, A., Banks, J., & Steptoe, A. (2011). Loneliness, social isolation, and behavioral  
580 and biological health indicators in older adults. *Health Psychology*, 30 (4), 377-85.
- 581 Shellito N., & Roldan, N.V. (2019). Walking away from loneliness: The mediating role of social  
582 isolation. *Innovation in Aging*, 3(1). S836-S837. Doi:  
583 <https://doi.org/10.1093/geroni/igz038.3082>.

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 584 Sheridan, D., Coffee, P., & Lavallee, D. (2014). A systematic review of social support in youth sport.  
585 *International Review of Sport and Exercise Psychology*, 7(1), 198–228.  
586 Doi:10.1080/1750984X.2014. 931999
- 587 Silverman, M. N., & Deuster, P. A. (2014). Biological mechanisms underlying the role of physical  
588 fitness in health and resilience. *Interface focus*, 4(5), 20140040. Doi:10.1098/rsfs.2014.0040.
- 589 Smith, A.K., Ayanian, J.Z., Covinsky, K.E., et al. (2011). Conducting high value secondary dataset  
590 analysis: an introductory guide and resources. *Journal of General International Medicine*,  
591 26(8), 920-29.
- 592 Snape D., & Martin, G. Office of National Statistics. (2018). Measuring loneliness: guidance for use of  
593 the national indicators on surveys. Downloaded on 30th January 2020 from:  
594 [https://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/methodologies/measu](https://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/methodologies/measuringlonelinessguidanceforuseofthenationalindicatorsonsurveys)  
595 [ringlonelinessguidanceforuseofthenationalindicatorsonsurveys](https://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/methodologies/measuringlonelinessguidanceforuseofthenationalindicatorsonsurveys)
- 596 Solmi, M., Veronese, N., Galvano, D., et al. (2020). Factors associated with loneliness: An umbrella  
597 review of observational studies. *Journal of Affective Disorders* (2020), Doi:  
598 <https://doi.org/10.1016/j.jad.2020.03.075>
- 599 Steptoe, A., Shankar, A., Demakakos, P., & Wardle, J. (2013). Social isolation, loneliness, and all-  
600 cause mortality in older men and women. *Proceedings of the National Academy of Sciences*,  
601 110 (15), 5797-801. Doi: 10.1073/pnas.1219686110. Downloaded on April 19, 2018 from  
602 [www.pnas.org/cgi/doi/10.1073/pnas.1219686110](http://www.pnas.org/cgi/doi/10.1073/pnas.1219686110).
- 603 Thurston, R.C., & Kubzansky, L.D. (2009). Women, loneliness, and incident coronary heart disease.  
604 *Psychosomatic Medicine*, 71(8), 836-42.
- 605 Tully, M.A., McMullan, I.I., Blackburn, N.E., et al. (2019). Is sedentary behavior or physical activity  
606 associated with loneliness in older adults? Results of the European-wide SITLESS study.  
607 *Journal of Aging and Physical Activity*. 19, 1-7. Doi: 10.1123/japa.2019-0311.

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 608 Umberson. D. (1987). Family status and health behaviours: Social control as a dimension of social  
609 integration. *Journal of Health and Social Behaviour*, 28, 306–19.
- 610 Victor, C. R., Scambler, S., Shah, S., et al. (2002). Has loneliness amongst older people increased? An  
611 investigation into variations between cohorts. *Ageing & Society*, 22(1), 1–13.
- 612 Victor, C. R., Bond, J., & Scambler, S. (2009). *The social world of older people*, Maidenhead: Open  
613 University Press.
- 614 Victor, C. (2011). Loneliness in old age: the UK perspective. Safeguarding the Convoy: a call to action  
615 from the campaign to end loneliness. Age UK Oxfordshire. Downloaded on April 30, 2019  
616 from <https://www.campaigntoendloneliness.org/wp-content/uploads/Safeguarding-the-Convoy.-A-call-to-action-from-the-Campaign-to-End-Loneliness.pdf>.  
617
- 618 Walseth, K. (2006). Sport and belonging. *International Review for the Sociology of Sport*, 41(3–4),  
619 447–64. Doi:10.1177/1012690207079510.
- 620 Weiss, R. (1975). *Loneliness: The Experience of Emotional and Social Isolation*. Cambridge, MA: The  
621 MIT Press.
- 622 Wenger, G.C., & Burholt, V. (2004). Changes in levels of social isolation and loneliness among older  
623 people in a rural area: a twenty-year longitudinal study. *Canadian Journal of Aging/la revue*  
624 *canadienne du vieillissement*. 23, 115–27.
- 625 Xu, S., Qiu, D., Hahne, J., Zhao, M., & Hu, M. (2018). Psychometric properties of the short-form UCLA  
626 Loneliness Scale (ULS-8) among Chinese adolescents. *Medicine*, 97(38), e12373.  
627 <https://doi.org/10.1097/MD.0000000000012373>
- 628 Yu, R., Cheung, O., Lau, K., & Woo, J. (2017). Associations between perceived neighborhood  
629 walkability and walking time, wellbeing, and loneliness in community-dwelling older Chinese  
630 people in Hong Kong. *International Journal of Environmental Research and Public Health*, 14,  
631 1199. Doi:10.3390/ijerph14101199.

## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

- 632 Yuan, K.H., & Bentler, P.M. (2000). Three likelihood-based methods for mean and covariance  
633 structure analysis with non-normal missing data. *Sociological Methodology*, 165-200.