

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

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## PHYSICAL ACTIVITY, LONELINESS &amp; SOCIAL ISOLATION

29 Abstract

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

40 Key words

41 physical activity; social isolation; loneliness; older adults

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## 51 Introduction

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

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

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76 studies (795 studies, and 746,706 participants) suggests an association between loneliness and  
77 dementia (relative risk, RR=1.26; 95%CI: 1.14-1.40, I2 23.6%), paranoia (odds ratio, OR=3.36; 95%CI:  
78 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.,  
79 2020). It is estimated that the social and healthcare benefits of addressing loneliness in the UK are  
80 approximately £900 per person per annum (Bernard, 2013). Consequently, there is a need to  
81 understand how this growing public health concern might be addressed.

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

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

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101 Victor & Bowling, 2011). For example, Pels et al.'s (2016) systematic review (n=37 studies) exploring  
102 the association between PA and loneliness found that PA can contribute to a decrease in loneliness  
103 and that loneliness itself might reduce the probability of being physically active. However, most  
104 studies included were cross-sectional (24 studies), with only seven longitudinal studies of which only  
105 three explored the effect of PA on loneliness. Also, previous studies have highlighted the dynamic  
106 nature of loneliness experienced by older adults, and so establishing the factors linked to loneliness  
107 within a life course or longitudinal perspective is important to better inform the design of more  
108 effective interventions in a rapidly ageing society (Solmi et al., 2020; Victor et al., 2009).

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

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115 Method

116 **Participants**

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

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125 13), and wave 3 (2014-15). In total, the household response rate was 62% (8504 participants) for wave  
126 one, 86% (7455 participants) for wave two, and 62% (6279 participants) for wave three.

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

**133 Assessment of Physical Activity (PA)**

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

**141 Assessment of loneliness, social isolation, and social asymmetry***142 Loneliness*

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

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148 Previous research suggests that the (20 item long-form) has a high internal consistency (coefficient a  
149 ranging from 0.89 to 0.94) and test-retest reliability over a 1-year period ( $r = 0.73$ ) (Russell, 1996). A  
150 short form version of the UCLA (UCLA-6) was also found to have a good test-retest reliability ( $r=0.66$ )  
151 (Xu et al., 2018). The direct measure included in this analysis is the modified version of the UCLA which  
152 assesses loneliness using five questions: How often do you feel left out?; How often do you feel  
153 isolated; How often do you feel in tune with the people around you?; How often do you feel you lack  
154 companionship?; and How often do you feel lonely? (often, some of the time, hardly ever). Higher  
155 scores indicate greater loneliness (score range 1-10).

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

159 *Social isolation*

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

167 *Social asymmetry*

168 To address the discrepancy between desired and actual social networks where someone may feel  
169 lonely whilst having a large social network, or not feel lonely despite having a lack of social network  
170 (McHugh et al., 2017), the UCLA and SNI measures (as described above) have been combined in a  
171 measure of social asymmetry. Social asymmetry is introduced as an interaction within the model such

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172 that the outcome variable of PA is affected by an individual's score on social isolation, but that effect  
173 also depends on the individual's score on UCLA.

**174 Covariates**

175 Research suggests that socio-demographic covariates of age (years), sex (male/female), marital status  
176 (single, married, widowed, divorced), employment status (yes/no), and education (primary,  
177 secondary, higher) play an important role in loneliness (Schrepft et al., 2019; Shvedko et al., 2018).  
178 Additionally, general health status measured using a self-reported question (how is your health?  
179 excellent/very good/good/fair/poor), and cognitive health (orientation, comprehension, attention,  
180 recall, and language skills) measured using the Mini Mental State Exam (MMSE; Folstein et al., 1975)  
181 were also included in the analysis (Schrepft et al., 2019; Shvedko et al., 2018).

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

**189 Statistical analysis**

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

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



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196 Model fit was evaluated using a Root Mean Square Error of Approximation (RMSEA)  $\leq 0.05$  with an  
197 upper limit (90% CI)  $\leq 0.08$ ; a Comparative Fit Index (CFI)  $\geq 0.95$ ; and a Standardised Root Mean Square  
198 Residual (SRMR)  $\leq 0.08$  (Hoyle, 1995). Where the levels of fit indices were not achieved, the  
199 modification indices were examined, and where appropriate, adjustments were made. Statistical  
200 significance was set at  $p < 0.05$ . A high estimate (Est) indicates a strong effect/relationship, whilst a low  
201 estimate indicates a weaker effect/relationship. All analyses were conducted in Mplus (version 7.4;  
202 Muthen & Muthen, Los Angeles, CA).

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

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## Results

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

213 81% of the sample reported that they rarely felt lonely, and mean scores for loneliness (UCLA: mean,  
214 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  
215 2.86, 0.88; wave 3 2.79, 0.91) indicated that the sample had low levels of loneliness and isolation. 52%  
216 of participants indicated that they did not participate in social activities. The model described the data  
217 well where fit statistics showed Root Mean Square Error of Approximation  $\leq 0.05$  (RMSEA=0.04) (with  
218 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  
219 Root Mean Square Residual  $\leq 0.08$  (SRMR=0.03) (Hoyle, 1995).

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

221 **Direct effects**

222 *Physical activity (Wave 1, 2, and 3)*

223 Table 2 shows that PA (VPA, MPA, or walking) did not have any statistically significant effect on the  
224 measures of loneliness (UCLA, self-rated loneliness) or social isolation excluding an effect between  
225 walking at wave two and UCLA at wave 3 (Est=-0.05; SE=0.02) where higher levels of walking  
226 reduced feelings of loneliness.

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

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

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

242 There were no statistically significant direct effects of the measures of UCLA or self-rated loneliness  
243 on any measure of PA (VPA, MPA, walking). However, social isolation at wave 1 had a statistically

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244 significant direct effect on VPA at wave two (Est=0.05; SE=0.02), and wave three (Est=0.07; SE=0.03);  
245 MPA at wave two (Est=0.05; SE=0.02); and walking at wave three (Est=0.07; SE=0.03).

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

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

248 *Loneliness and Physical activity*

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

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

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

266 Additionally, a statistically significant total relationship between social isolation at wave one and  
267 walking at wave three (Est=0.06; Est=0.02) was shown via the indirect effect of walking at wave two

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268 (Figure 1: path G+B), social isolation at wave 3 (Figure 1: path C+H), VPA at wave two and social  
 269 isolation at wave three (Figure 1: path G+F+I), MPA at wave two and social isolation at wave three  
 270 (Figure 1: path G+F+I), walking at wave two and social isolation at wave three (Figure 1: path G+F+I),  
 271 and the direct effect between social isolation at wave one and walking at wave three (Figure 1: path  
 272 J).

273 The results also showed that age (VPA: Est=-0.01; SE=0.01; MPA: Est=-0.08; SE=0.02; walking: Est=-  
 274 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)  
 275 and health status (VPA: Est=-0.63; SE=0.10; MPA: Est=-0.58; SE=0.12; walking: Est=-0.63; SE=0.09)  
 276 were statistically significant for all PA levels. Social participation was statistically significant for VPA  
 277 (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  
 278 (Est=0.18; SE=0.09) were statistically significant for walking only.

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

## 287 Discussion

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

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## 293 Summary of findings

294 Loneliness and social isolation are related but different concepts (McHugh et al., 2017; Perlman &  
295 Peplau, 1981), and distinguishing between the two concepts is important because it allows more  
296 targeted interventions to be identified. For example, this analysis shows that higher levels of social  
297 isolation, not loneliness were directly associated with lower levels of walking over six years, MPA over  
298 three years and VPA over three and six years. Social isolation also had a total effect on walking, MPA,  
299 and VPA via its effect on PA and social isolation over six years. Additionally, higher levels of walking  
300 were associated with lower levels of loneliness based on a modified version of the UCLA scale over a  
301 3-year period.

302 National PA guidelines encourage increased levels of PA for mental health benefits such as decreased  
303 depression and loneliness (Care DoHas, 2019), and the results from this study support this, with the  
304 finding that increased levels of walking may reduce feelings of loneliness in older community-dwelling  
305 adults, over a 3-year period. This finding is further supported by cross-sectional analyses (Shellito &  
306 Roldan, 2019: n=6,157 participants; Yu et al., 2017: n = 181 participants). Our study also found no  
307 association between MPA or VPA with the measures of loneliness or social isolation which is supported  
308 by a previous systematic review and meta-analysis of clinical trials exploring the effects of PA  
309 interventions on social isolation, loneliness and low social support in older adults (Schvedko et al.,  
310 2018: n= 38 studies; 5288 participants; 51–82 years), as well as a recent clinical trial exploring the  
311 effects of an exercise referral programme on PA and health of older adults (Tully et al., 2019: n=1360  
312 participants; mean age 75 years). However, whilst walking is considered a safe and popular form of  
313 increasing PA (Arnardottir et al., 2013; Department of Health 2011; Franco et al., 2015) consensus as  
314 to which types of PA contribute to the classifications of light (LPA), MPA or VPA is lacking. Walking for  
315 example, can be classed as either low, moderate, or vigorous and so there may be an overlap across  
316 classifications within studies (Milton et al., 2018). Future research should seek to understand the type  
317 of PA to more fully understand the effects of different intensities of walking in relation to loneliness.

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318 Additionally, it is not possible to identify whether the walking activity was carried out in a group setting  
319 and therefore it is not possible to establish whether this finding supports loneliness reduction theories  
320 in the context of PA. Consequently, further studies exploring walking within individual or group setting  
321 should be explored.

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

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

342 Strengths and limitations

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343 Previous studies have highlighted the dynamic nature of loneliness and social isolation experienced  
344 by older adults, and so understanding the association between PA and both loneliness and social  
345 isolation within a life course perspective is important to better inform the design of more effective  
346 interventions in a rapidly aging society (Victor et al., 2009; Wenger & Burholt, 2004). Another key  
347 strength of this study is that it uses a quasi-simplex path analysis which simultaneously estimates both  
348 direct and indirect associations therefore enabling exploration of the reciprocal relationship between  
349 self-reported PA and measures of loneliness using longitudinal data over a 6-year period. Additionally,  
350 this analysis addresses the discrepancy between desired and actual social networks by combining the  
351 measures of loneliness (UCLA) and social isolation to form a measure of social asymmetry (McHugh et  
352 al., 2017) and introducing this as an interaction within the model such that the outcome variable of  
353 PA is affected by an individual's score on social isolation, but that effect also depends on the  
354 individual's score on UCLA. This study is one of the first studies to explore social asymmetry and PA,  
355 and whilst finding no association, further investigation is warranted.

356 In terms of limitations however, the TILDA dataset has not been specifically designed to address the  
357 research question of this current study, but provides repeated measures of the same individuals and  
358 so is an opportunity to explore the research question in a less expensive and time intensive way than  
359 would be possible using a study design that includes prospective data collection (Smith et al., 2011).  
360 Additionally, the model assumes factorial invariance of the measures (Hays et al., 1994; Selig & Little,  
361 2012), and as this study includes only observed measures, it is not possible to test the assumption of  
362 factorial invariance. Consequently, the findings should be considered with caution and future research  
363 should consider including multiple measures to create a latent construct to address measurement  
364 error (Selig & Little, 2012). Additionally, the measures included in the analysis may give rise to bias.  
365 For example, the model includes repeated measures across time which may address factorial  
366 invariance but may give rise to a retest effect (Selig & Little, 2012). The measures are also subjective  
367 and may be influenced by health status, mood, depression, anxiety, or cognitive ability, as well as  
368 seasonal variation, social desirability, (Dyrstad et al., 2014; Murphy, 2009; Saelens et al., 2012).

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369 Furthermore, inaccuracy of self-reported PA may be more exaggerated among older adults because  
370 of recall error (Dyrstad et al., 2014; Murphy, 2009; Saelens et al., 2012). However, despite these  
371 concerns, self-reported PA has shown to have convergent validity with objective measures of PA in  
372 older adults (87–89 years) (Innerd et al., 2015).

373 This study also assumes that all the important predictors are included in the analysis, but there are  
374 many determinants of human behaviour which may potentially confound the results (Selig & Little,  
375 2012) and as with any observational study we cannot rule out the potential for residual confounding.  
376 Future studies should, where possible, consider objective measures and additional predictors over  
377 time to address some of these biases (Bauman et al., 2009).

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

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

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



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## 394 Conclusion

395 A key message from this study is that social isolation, and not loneliness, is associated with lower levels  
396 of PA (VPA, MPA, and walking) over time. This finding supports the importance of social support  
397 provided through PA participation and proposes that lack of social networks reduces both self-  
398 regulatory and social control processes that in turn reduce healthy behaviours such as PA. Future  
399 research should seek to add to the understanding of loneliness and social isolation within the context  
400 of PA using an intervention study to explore a walking intervention for older adults and explore the  
401 effects of different setting (e.g. group versus individual) on loneliness and social isolation over time.

402

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