The Role of Physical Activity and Sedentary Behavior in Predicting Daily Pain and Fatigue in Older Adults: A Diary Study

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Abstract

Background. Little attention has been paid to within-person daily associations amongst light physical activity (PA), moderate-to-vigorous physical activity (MVPA), and sedentary behavior (SB) with subsequent bodily pain and fatigue. Daily reports of pain and fatigue are less likely to be affected by recall bias and to conflate days of high and low pain/fatigue into one overall score.

Purpose. To examine daily within-person associations between pain, fatigue and physical health and ascertain whether such associations are moderated by individual differences in these variables.

Methods. Participants were 63 community-living older adults (female $n = 43$, mean age = 70.98 years). Questionnaires measured typical levels of PA, SB, bodily pain, fatigue and physical health. Subsequently, on a daily basis over a 1-week period, participants' levels of light PA, MVPA and SB were measured using accelerometers. Participants completed a questionnaire rating their pain and fatigue at the end of each day.

Results. Multilevel modelling revealed positive within-person associations between daily light PA, daily MVPA, and pain, as well as negative within-person associations between daily SB and pain. For individuals with higher typical levels of fatigue, there was a negative association between daily light PA, MVPA and fatigue. For individuals with better levels of physical health, there was also a negative association between daily MVPA and fatigue. For those with higher typical levels of fatigue and better levels of physical health, there was a positive association between daily SB and fatigue. No such interaction effects were found between high levels of typical pain and PA or SB.

Conclusions. Our findings indicate that efforts to promote daily PA in older adults might be more effective for those who report high typical levels of fatigue and physical health, compared to those who report high levels of daily physical pain.

39   *Keywords:* accelerometers, diary studies, physical health, sedentary behavior

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According to the United Nations [1], the number of older adults (≥ 60 years) worldwide is

expected to increase from 901 million in 2015 to 1.4 billion by 2030. As adults age, they are

more likely to experience negative health outcomes (e.g., heart disease, back pain) [2]. For

example, evidence shows that many older adults in community settings suffer from bodily

pain (63% in men, 91% in women) [3] and fatigue (15% in men, 29% in women) [4]. Bodily

pain has been found to be negatively related to walking speed, balance and physical

functioning in older women in community settings [5]. With regard to fatigue, positive

associations have been reported between this variable and negative health conditions (e.g.,

arthritis) in older adults [6].

It is well documented that lifestyle factors such as physical activity (PA) and

sedentary behavior (SB) can play an important role in determining health-related quality of

life in older adults [7]. Evidence shows a positive association between engaging in moderate-

to-vigorous PA (MVPA) and improved physical health (e.g., decreased risk of mortality,

stroke, type 2 diabetes) [8] and mental health (e.g., fewer depression symptoms) in older

adults [9]. In light of recent literature that has identified a high prevalence of light PA in the

general public [10], particularly in older adults, research has also examined the role of light

PA in improved physical health. Previous studies have reported positive associations between

engagement in light PA and the reduction of coronary heart disease in adults and older men

[11], as well as fewer depression symptoms in older adults [9].

In contrast, spending a large proportion of the day in SB among older adults (age 70-

85; men 67.8%, women: 66.3%) [12] can have a negative impact upon health. For example,

Stamatakis et al. [13] found that engagement in self-reported SB was associated with a higher

cholesterol ratio, BMI, and waist circumference in older adults. Taken together, this evidence

indicates that lifestyle factors such as light PA, MVPA and lower SB are important predictors

65 of health. Evidence has also accumulated regarding the role of light PA, MVPA and SB in

66 predicting two important indices of health, namely, bodily pain and fatigue.

67 **Physical Activity, Sedentary Behavior and Bodily Pain**

68 Engagement in self-reported PA has been related to less back pain in older adults [14]. In line

69 with this, PA is recommended as a treatment for chronic pain [15]. Additionally, higher

70 levels of sitting time have been associated with worse bodily pain in community-living older

71 adults [16]. However, the associations between pain and PA are complicated and seem to be

72 influenced by the level at which these associations are investigated. For example, exploration

73 of within-person associations in older adults revealed that daily levels of PA were a

74 significant predictor of higher levels of daily pain in women, even though overall/typical PA

75 was associated with lower levels of pain [17]. In line with this finding, there is also evidence

76 that some older adults who report that activity worsens their pain, also use exercise to manage

77 their pain [18]. Interestingly, the interference of pain with activity was particularly evident in

78 those with severe levels of pain [18], suggesting that typical pain could influence the

79 association between daily pain and daily PA. Within-subject analyses can be used to explore

80 the associations between daily pain and daily PA in more detail, while exploring the

81 moderating influence of typical pain on these associations [17]. In addition, given the

82 negative associations between physical health and pain [19] and between physical health and

83 SB [20], as well as the positive associations between physical health and PA [21], it is also

84 important to examine the moderating influence of physical health in the association between

85 daily PA/SB and daily pain.

86 Daily self-reports are less likely to be affected by recall bias and to conflate days of

87 high and low pain into one overall score of pain. Further, by separating within-person from

88 between-person associations, it is possible to ascertain the degree to which variables correlate

89 with each other within the same individual over time, without such correlations being

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influenced by between-person differences in the levels of these variables [22]. As noted by

Curran, Howard, Bainter, Lane, and McGinley [23], virtually all theories in the psychological

sciences postulate joint within- and between-person processes. Omitting either of these two

components results in a disjunction between theory and statistical testing. From an applied

perspective, understanding true within-person associations over time helps to develop more

tailored interventions.

Physical Activity, Sedentary Behavior and Fatigue

Several studies have shown that fatigue is associated with restricted activities [24], lower

levels of PA [25,26], and more dependency in activities of daily living [27]. With regard to

SB, it has been shown that sedentary adults report higher levels of fatigue compared to active

adults [28,29]. There is also evidence that exercise interventions can reduce fatigue in adults

aged 55 and older, and that the improvements in fatigue are related to the improvements in

PA [26]. Similar to the research on pain, however, the relation between fatigue and PA has

been mainly examined at the between-person level. Nevertheless, feelings of fatigue can vary

at the within-person (i.e., daily) level [30], and these within-person changes in fatigue are

negatively related to changes in PA [31]. Interestingly, levels of typical fatigue have also

been negatively related to diurnal PA patterns and physical health (chronic conditions) [32],

suggesting that when exploring the associations between fatigue and PA at within-person

level, typical levels of fatigue and physical health should be taken into account.

Purpose of the Study

Our aim was to examine the relation between daily (over a 7-day period) light PA, MVPA,

and SB, and subsequent bodily pain and fatigue. We also investigated whether such

associations were moderated by individuals' typical levels of bodily pain, fatigue and

physical health. This is the first attempt to examine within-and between person associations

of light PA, MVPA and SB with subsequent bodily pain and fatigue in older adults. It was

115   hypothesized that daily light PA and MVPA would predict lower levels of daily pain,

116   whereas daily SB would predict higher levels of pain, but only for those with low levels of

117   typical pain and high levels of physical health. In addition, it was hypothesized that daily

118   light PA and MVPA would predict lower levels of fatigue, whereas daily SB would predict

119   higher levels of fatigue, but only for those with low levels of typical fatigue and high levels

120   of physical health.

Method

122 Participants

123   Older community-dwelling adults ($n = 67$) in the UK were recruited. Inclusion criteria were

124   that participants did not use a walker or a wheelchair and were above the age of 60 years.

125   Simulation studies (e.g., McNeish & Stapleton; Maas & Hox) [33,34] indicate that $N > 50$ at

126   level 2 (participants in our case) of a multilevel model, provides adequate power for variance,

127   standard error and fixed effects estimates. A list of contacts was provided to the researchers

128   from a database of about 1000 volunteers who were registered with a UK university as

129   potential participants for studies on ageing-related topics. Participants were sent invitation

130   letters and/or emails. In total, 63 participants ($n = 63$, $M_{age} = 70.98$, $SD = 6.92$, female =

131   68.3%) were included in the analysis, after four participants were excluded (not sufficient

132   accelerometer wear time = 2, using a walker = 2) from the analysis. As can be seen in Table 1,

133   the participants had an average body mass index (BMI; kg/m^2) of 25.14 ($SD = 3.47$), were

134   well educated (highest degree obtained = a post-graduate degree; 28.6%), and had a

135   comfortable income (£20,000-£35,000 = 34.9%). The participants were mostly white and

136   British (79.4%) and more than one-third of the participants were co-habitating (65.1%) with

137   their partner. Many participants (57.1%) reported having been diagnosed with a

138   cardiovascular condition.

139 Procedures

140   Ethical approval for this study was granted by the Ethical Review Committee at a UK

141   university. An introductory session about the study took place in an initial session in a lab or

142   in a convenient place for the participant. The participants signed written consent forms. Their

143   weight and height were then measured to calculate BMI (kg/m^2) using a portable scale

144   (TANITA BC-545N). Two participants refused to be measured, and their self-reported

145   weight and height were recorded. At the beginning of the study, a set of questionnaires was

146   distributed to the participants, to provide pre-diary typical measures of the study variables,

147   including demographics. Further, either a palmtop computer (Scroll Pocket Tablet PC) or a

148   smartphone (ZTE Blade Q Mini Android Smartphone), depending on equipment availability,

149   was given to the participants for the daily assessments. The devices were programmed to

150   prompt a set of daily questions between 4 pm and 9 pm every day on a random basis. The

151   devices had touch-screens which participants had to tap to record an answer. If the

152   participants did not respond to the first alarm, a second alarm was provided 2 minutes later. If

153   there were no answers, the question was treated as missing ($n= 45$). Answers that were

154   outside of the alarm range due to system errors were treated as missing ($n= 1$). The answers

155   were stored within each participant's device. At the end of the data collection, research staff

156   downloaded the answers from the devices to a lab-based desktop computer. In addition to the

157   touchscreen devices, an accelerometer was distributed to the participants to wear over seven

158   days during waking hours. Participants were instructed to wear the monitor on their right hip,

159   to avoid wearing the accelerometer during any water activities, and to record in a diary each

160   time point when they started and stopped wearing the accelerometer.

161   **Measures**

162   *Demographics*

163   We asked participants to tick whether they were diagnosed with any cardiovascular disease

164   over the past 12 months. We assessed the occurrence (*have* = 1, *do not have* = 0) of high

165 cholesterol, heart disease, vascular disease, high blood pressure and circulatory problems. In

166 addition, gender (*male* = 0, *female* = 1) and marital status (*living alone* = 0, *living with*

167 *someone else* = 1) were coded.

Typical and daily bodily pain

169 For typical pain, participants were asked to complete the two pain items from the RAND 36-

170 Item Health Survey [35] [i.e., "How much bodily pain have you had during the past 4 weeks?"

171 ranging from 1 (*none*) to 6 (*very severe*), and "During the past 4 weeks, how much did pain

172 interfere with your normal work (including both work outside the home and housework)?",

173 ranging from 1 (*not at all*) to 5 (*extremely*)]. The coefficient alpha (α) was 0.78 in a previous

174 study [35] and α = 0.79 in the present study. Items were averaged for our analysis. To

175 measure daily bodily pain, we asked one item: "How much bodily pain do you have right

176 now?", and responses were rated on a 1 (*no pain*) to 4 (*severe pain*) scale.

Typical and daily fatigue

178 The Multi-Dimensional Fatigue Index (MFI-20) [36] was utilized to assess fatigue over the

179 previous 4 weeks with a total of 20 items. The scale tapped five dimensions of fatigue:

180 general fatigue (e.g., "I feel tired"), physical fatigue (e.g., "Physically, I feel able to only do a

181 little"), reduced activity (e.g., "I think I do very little in a day), mental fatigue (e.g., "My

182 thoughts easily wander"), and reduced motivation (e.g., "I don`t feel like doing anything).

183 Answers were rated on a 5-point scale from 1 (*yes, that is true*) to 5 (*no, that is not true*).

184 Good internal reliability coefficients were found in a previous study (α range: 0.75-0.94) [36]

185 and in the present study (α range: 0.67-0.83). Subscales were summed to calculate a total

186 fatigue score. To assess daily fatigue, one item ("How much fatigue do you feel right now?")

187 was chosen from the MFI and was answered at each beep. Participants provided a rating from

188 1 (*no fatigue*) to 4 (*severe fatigue*).

Daily physical activity and sedentary behavior

190   Accelerometers were used to monitor PA and SB levels (model GT3X+ was worn by 47

191   participants and model WGT3X-BT was worn by 16 participants). The two models have been

192   shown to produce very similar results [37], and this was also the case in our study according

193   to the results of one-way MANOVA (Pillai's trace = 0.01, F (3, 59) = 0.19, p = .91, follow-

194   up univariate ANOVAs: SB: F (1, 61) = 0.19, p = .67, light PA: F (1, 61) = 0.00, p = .98, and

195   MVPA: F (1, 61) = 0.1, p = .76). Hence, in our analysis we combined the data from the two

196   types of accelerometers. Participants who wore the accelerometer a minimum of 10 hours a

197   day for 5 days, including 1 weekend day over 7 days, were included in the analysis Data were

198   extracted using the ActiGraph software. The researcher programmed the monitor to

199   accumulate movement data every 60 seconds. Non-wear time was classified as 90 minutes of

200   consecutive non-activity counts (< 100 counts) with 2 minutes of tolerance allowance

201   [38].Based on the diary the participants recorded, we set a time filter to standardize wearing

202   time (7:30 am to 10:30 pm). For the purposes of our analysis, for each day and for each

203   participant, we utilized the movement data accumulated from the morning until the time they

204   answered the daily questions on bodily pain and fatigue. Hence, in our analysis daily PA and

205   SB were used as predictors of daily bodily pain and fatigue.

206   Counts per minute were processed to categorize the thresholds of activities [i.e., SB:

207   0-99 counts per minute (cpm) [12] light PA: 100-2019 cpm, moderate PA: 2,020-5,998 cpm,

208   and vigorous PA: ≥5,999 cpm [39]. Moderate and vigorous intensities were summed to

209   represent MVPA. Finally, each activity category (light PA, MVPA, and SB) was divided by

210   the total wear days and then multiplied by 100 to represent the proportion of each activity

211   category, in order to reduce inter-participant variability [10,40]. These proportion scores were

212   used in the main analysis.

213   ***Typical health status***

214 The RAND 36-Item Health Survey was administered to measure physical health [35].

215 Participants were told: "The following questions are about activities you might do during a

216 typical day. During the past 4 weeks, has your health limited you in these activities? If so,

217 how much?" Rating scales varied depending on items (e.g., carrying groceries). Higher scores

218 on the fours subscales represented better physical health [35]. Good internal consistency

219 coefficients have been found in adults (mean age = 30.54, α = 0.89) [41] , and this was also

220 the case in the current study (α = 0.75).

221 *Typical physical activity*

222 Typical PA was assessed using the Physical Activity Scale for the Elderly (PASE) [42] . In

223 total, 18 items were rated using 4-point scales (hours/week) (e.g., "How much time was spent

224 on the activity over the last 7 days?") and yes/no questions (e.g., "Have you performed 'light

225 housework' over the last 7 days?"). The items captured 7 dimensions of PA (e.g., walking,

226 light sport/recreation). Items were multiplied by the number of hours the participants spent

227 and were weighted and summed to obtain an overall score of PA [43]. People with higher

228 scores were more physically active. Acceptable Cronbach's alpha for reliability was 0.73 in a

229 previous study with older adults [44], but somewhat lower in our study (α = .56).

230 *Typical sedentary behavior*

231 Typical sedentary time was assessed with seven items from the Measure of Older adults`

232 Sedentary Time (MOST) [45]. The survey asked the participants to record their total

233 sedentary time (hours and minutes) over the previous seven days (e.g., watching television).

234 Items were summed with higher scores representing higher levels of SB. Test-retest

235 reliability was found to be acceptable (Intra-class correlation coefficient = 0.52, 95%

236 confidence interval = 0.27-0.70) in older adults [45]. The Cronbach's alpha coefficient is not

237 applicable for this scale.

238 **Data Analysis**

239 Linear mixed models (IBM SPSS, version 22) were tested to examine within- and between-

240 person associations between light PA, MVPA, and SB with bodily pain and fatigue. We ran

241 four models in total. In the first two, light PA and MVPA predicted bodily pain and fatigue

242 respectively, and in the other two models SB predicted pain and fatigue respectively. Within-

243 person predictors (level 1; daily light PA, daily MVPA, and daily SB) were person-mean

244 centered. At level 2, the average of daily light PA, daily MVPA and daily SB over the 7 days

245 were entered as predictors. By including the predictor average scores over the 7-day period at

246 level 2, the level 1 within-person associations were not conflated by between-person

247 differences [22]. In addition, we tested the cross-level interactions between each of the level 1

248 predictors with typical pain (when predicting daily pain), with typical fatigue (when

249 predicting daily fatigue), and with physical health (when predicting daily pain and fatigue).

250 BMI, age, presence/absence of cardiovascular disease, gender and co-habitating were also

251 entered at level 2 as covariates. Level 2 predictors were uncentered [46]. All level 1 and 2

252 predictors, apart from the categorical ones, were converted into Z scores to obtain β

253 coefficients from the analysis. R_1^2 was estimated as an effect size, representing the amount of

254 variance at level 1 explained by the predictors, compared to the variance explained by a

255 model with only the intercept [47].

Results

257 Participants completed 341 (77.3%) out of 441 (over seven days) daily questions on bodily

258 pain and fatigue. The percentage of missing cases for the pre-diary survey was around 3.2%.

259 The skewness scores for the dependent variables of bodily pain (1.89) and fatigue (0.93) were

260 within an acceptable range (skewness ±2) [48]. Daily light PA and SB were highly correlated

261 (r= -0.83, p< 0.01) as is often the case in the literature; hence, separate models for light PA

262 and SB were run.

263   Table 2 shows that the participants wore accelerometers for almost 10 hours (594.13

264   minutes) before they answered the daily questions. The participants spent most of their time

265   in SB (58.58%) and light PA (35.80%), with a lower proportion of MVPA (5.62%).

266   According to R_1^2, models 1 and 2 (Table 3) predicted 52.8% (bodily pain) and 21.0% (fatigue)

267   of the variance at level 1. Also, models 3 and 4 (Table 4) accounted for 54.8% (bodily pain)

268   and 19.1% (fatigue) of the variance.

269   **Daily light PA, MVPA, and daily SB Predicting Bodily Pain**

270   Table 3 shows the standardized coefficients (β) and standard errors for level 1 and level 2

271   predictors of bodily pain. Engagement in daily light PA ($\beta= 0.151$, $p= 0.009$), daily MVPA

272   ($\beta= 0.110$, $p= 0.023$), and higher levels of typical pain ($\beta= 0.543$, $p<0.001$) positively

273   predicted bodily pain experienced at the daily level. No other significant associations were

274   found. Typical bodily pain and physical health did not significantly moderate the associations

275   between daily light PA, MVPA, and bodily pain. Table 4 shows that typical pain ($\beta= 0.515$,

276    $p<0.001$) and daily SB ($\beta= -0.182$, $p= 0.003$) over the 7 days predicted bodily pain at the

277   daily level. No other associations were significant.

278   **Daily light PA, MVPA, and SB Predicting Fatigue**

279   Table 3 depicts that daily light PA and MVPA did not significantly predict fatigue. However,

280   a number of significant interactions emerged. Those interactions were further probed via

281   simple slope analyses, for which we report unstandardized coefficients. Specifically, for

282   individuals with lower levels of typical fatigue, there was a positive association between daily

283   light PA and daily fatigue (B = 3.28, $p< 0.001$), whereas for those with higher levels of

284   typical fatigue, this association was negative (B = -3.22, $p= 0.001$). For those with lower

285   levels of typical fatigue, there was also a positive association between daily MVPA and daily

286   fatigue (B = 3.49, $p< 0.001$), whereas for those with higher levels of typical fatigue, this

287   association was negative (B = -3.41, $p< 0.001$). For individuals with lower typical levels of

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288   physical health, there was a positive association between daily MVPA and fatigue (B = 2.93,

289   p= 0.027), whereas for those with higher levels of typical physical health, this association

290   was negative (B = -2.85, *p*= 0.034). Typical levels of physical health did not significantly

291   interact with light PA to predict daily fatigue. With regard to main effects, typical fatigue (*β*=

292   0.263, *p*= 0.031) and cardiovascular disorder (*β*= 0.483, *p*= 0.014) were also significantly

293   associated with daily fatigue.

294   Simple slope analyses were also conducted to probe significant interactions in Table 4.

295   Specifically, for individuals with lower typical levels of fatigue, there was a negative

296   association between daily SB and fatigue (B = -4.612, *p*< 0.000), whereas for those with

297   higher levels of typical fatigue, this association was positive (B = 4.513, *p*<0.000). For

298   individuals with lower typical levels of physical health, there was a negative association

299   between daily SB and fatigue (B = -3.779, *p*= 0.019), whereas for those with higher levels of

300   typical physical health, this association was positive (B = 3.680, *p*= 0.022). With regard to

301   main effects, typical fatigue (*β*= 0.274, *p*= 0.026) and the presence of cardiovascular diseases

302   (*β*= 0.489, *p*= 0.013) also predicted daily fatigue.

Discussion

304   In this study we examined daily associations between objectively-assessed light PA, MVPA,

305   and SB, and subsequent bodily pain and fatigue in a sample of older adults. Further, we

306   explored whether these within-person associations were moderated by between-person

307   differences in typical bodily pain, fatigue and physical health.

Predictors of Bodily Pain

309   We expected that daily light PA and MVPA (and SB) would be negative (positive) predictors

310   of daily pain, but only for those with low levels of typical pain and better levels of health.

311   Contrary to our hypothesis, the within-person associations of daily light PA and MVPA with

312   daily bodily pain were positive, in that more engagement in daily light PA and MVPA

313 predicted more subsequent bodily pain. However, this finding is in line with a previous study

314 in which a positive within-person association was found between PA and pain in a sample of

315 older adults [17]. With respect to daily SB and bodily pain, the analysis showed that more

316 engagement in daily SB was associated with less subsequent bodily pain in older adults. This

317 finding is aligned with our results pertaining to PA and pain.

318 Even though engagement in PA might predict higher levels of bodily pain in the short

319 term in older adults, it is well established that regular PA can maintain and improve health in

320 older adults [49,50]. In fact, there are studies showing a negative as opposed to a positive

321 association between PA and pain (e.g., Cecchi et al. [14]). Given these apparently

322 inconsistent findings regarding the associations between PA and pain, more research is

323 needed to explore the temporal effects of PA on pain in more detail. Future studies may need

324 to utilize more frequent measurement points (e.g., hourly). Given some reports that feelings

325 of pain can fluctuate throughout the day [50], it is possible that PA/SB might predict pain in

326 different ways depending on the time of the day. It would also be interesting to explore the

327 impact of the type of activity on the associations between PA and pain. For example, lifting

328 heavy objects and gardening could have differential effects on the relationship between pain

329 and PA.

330 Finally, typical physical health did not moderate the associations between pain and

331 PA or SB. It should be acknowledged though that the overall perceived physical health of the

332 participants was good (i.e. 81 out of 100). Therefore, in order to explore this hypothesis in the

333 future it is important to include a sample with a greater variation in perceived physical health.

334 **Predictors of Fatigue**

335 We expected that daily light PA and MVPA (and SB) would be negative (positive) predictors

336 of daily fatigue, but only for those with low levels of typical fatigue and better levels of

337 physical health. The results partially supported our hypotheses. There were no significant

338   within- and between-person associations between light PA, MVPA, SB and subsequent

339   fatigue. Other studies have generally reported modest negative associations between fatigue

340   and PA [25,51]. Such modest and/or non-significant associations could be due to the

341   possibility that the relations between PA, SB and fatigue are dependent on individuals' levels

342   of health and their general levels of fatigue.

343   Better typical levels of physical health moderated the association between daily

344   MVPA and fatigue, and between SB and fatigue. As hypothesized, those who engaged in

345   more MVPA and less SB reported less fatigue, but this was the case only for individuals with

346   better perceived health. In contrast, for those with worse perceived health, engagement in

347   more MVPA and less SB was detrimental as it resulted in more daily fatigue. Interestingly,

348   physical health did not moderate the association between light PA and fatigue. These findings

349   suggest that intensive forms of PA should be reserved for those in better physical health,

350   while those in lower physical health should initially be prescribed light PA. Given that

351   physical health did not influence the associations between light PA and fatigue, perhaps light

352   PA would be the most suitable type of PA to start an intervention to reduce fatigue for older

353   adults. Increasing light PA might not only benefit levels of fatigue and physical health, but it

354   is also a feasible target for older adults who are not active.

355   Contrary to our hypothesis, the expected negative (positive) association between daily

356   light PA (SB) and subsequent daily fatigue were evident only for those individuals with high

357   (as opposed to low) typical fatigue levels. The current findings suggest that those with higher

358   typical levels of fatigue might benefit more in terms of their daily fatigue levels from moving

359   more and sitting less than those with lower levels of typical fatigue. Even though exercise

360   interventions have been shown to reduce the levels of fatigue [52], even in clinical

361   populations with high levels of fatigue such rheumatoid arthritis [53] and multiple sclerosis

362   [54], to our knowledge little attention has been paid to the moderating role of typical levels of

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363 fatigue on these benefits. Therefore, the possibility that those with higher levels of typical

364 fatigue might benefit more from being physically active in terms of their daily fatigue should

365 be investigated in future intervention studies. Our findings also highlight the need to focus

366 PA-promoting interventions in older adults on individuals who report high levels of fatigue

367 and perhaps experience chronic fatigue. Given that higher levels of light PA were associated

368 with lower levels of fatigue in those with higher levels of typical fatigue, perhaps PA-

369 promoting interventions for this particular population should focus on light PA. As

370 mentioned above, this is likely to be a feasible target for people who are not physically active,

371 and such type of activity can help to increased overall health [55,56].

Limitations and Future Research Directions

373 We must acknowledge some limitations of the present study. The standardized coefficients

374 associated with the main effects of daily SB, light PA and MVPA were small. However, such

375 effects are in line with our research in the pain and fatigue literatures utilizing objective

376 assessments of PA [25,51]. Given that our participants were generally inactive, 1 SD

377 increases in daily SB, light PA and MVPA represent substantial deviations from the sample's

378 mean scores on those variables. It should be also considered that objective PA and self-

379 reported pain and fatigue do not share common method variance, as is the case with self-

380 reported PA. Another limitation of the study is that due to its short duration (7 days), we do

381 not know the extent to which our findings would generalize over a longer period of time (e.g.,

382 two or three months). A measurement burst approach [57] in which diaries are administered

383 on multiple occasions (e.g., 3 weeks over a year) would allow for a test of seasonal effects

384 (e.g., due to the weather). Assessing multiple activities and rates of fatigue and pain

385 throughout the same day can also offer a more comprehensive understanding of the dynamic

386 nature of the relations between these two variables, PA and SB. In addition, objectively-

387 assessed PA cannot readily differentiate between different modes of activity (e.g., lifting

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388 heavy objects vs. playing with children) which can predict variations in perceptions of pain

389 and fatigue. Another limitation of the study was that the sample was rather ethnically

390 homogenous, relatively educated, relatively healthy (e.g., low bodily pain and fatigue scores),

391 quite wealthy, and thus not wholly representative of the general population of older adults in

392 the UK. Future studies should aim to recruit older adults from more diverse backgrounds.

393 Further, another limitation was that we used self-reported measures of health. In future

394 investigations, it might be informative to replicate our study using objective assessments of

395 physical health (e.g., field- based tests of gait speed or hand grip strength).

396 Notwithstanding the limitations above, this study has several strengths. This is the first study

397 to examine within-person associations between light PA, MVPA, SB and subsequent daily

398 pain and fatigue in older adults. We were able to establish support for such within-person

399 associations which were not confounded by individual differences in PA and SB. In addition,

400 advancing past research, we specifically measured light PA because in older adults a high

401 proportion of time is spent engaging in this type of PA [10,58]. Indeed, we found that

402 engagement in daily light PA represented 35.80% of the daily activity up to the measurement

403 of pain and fatigue, a much higher percentage than that for MVPA (5.62%). We measured

404 levels of PA and SB both objectively and via self-reports. In contrast, most of the previous

405 studies have only used self-reports of PA and/or SB in predicting bodily pain and fatigue. By

406 using smart devices for EMA, we were able to obtain real-time reports of pain and fatigue.

407 Future studies in this field could build on our findings to develop targeted PA interventions

408 for individuals with varying levels of fatigue and pain. Such interventions could use modern

409 technology (e.g., smartphones) to target beliefs, barriers and benefits of being more

410 physically active and less sedentary.

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580

Table 1

Participant Characteristics

Variable	
Sex, *n* (%)	63; female = 43 (68.3)
Age, mean (SD)	70.98 (6.92)
Education completed, *n* (%)	Missing 4 (6.3)
Primary	7 (11.1)
Secondary	10 (15.9)
Higher	15 (23.8)
Post graduate	18 (28.6)
Other	9 (14.3)
Annual income, *n* (%)	
Below £20,000	22 (34.9)
£20,000 -35,000	22 (34.9)
£35,000 – 45,000	11 (17.5)
Above 45,000	8 (12.7)
Ethnicity, *n* (%)	
White British	50 (79.37)
Other White	2 (3.17)
Black Caribbean	1 (1.59)
Indian	7 (11.11)
Other	3 (4.76)
BMI (kg/m^2), mean (SD)	25.14 (3.47)
Cardiovascular disorder (%)	0 = have (57.1), 1 = do not have (42.9)
Cohabiting with partner (%)	0 = no (34.9), 1 = yes (65.1)

584   Table 2

585   *Descriptive Statistics and Intraclass Correlation Coefficients for Study Variables*

	M	*SD*	ICC	*Min*	*Max*
1. Daily accelerometer wear time (min/day)	594.13	115.27	-	-	-
2. Daily SB (% waking time)	58.58	13.44	0.93	-	-
3. Person-mean SB (%)	59.15	10.70	-	-	-
3. Daily light PA (% waking time)	35.80	11.61	0.90	-	-
4. Person-mean light PA (%)	35.43	8.79	-	-	-
5. Daily MVPA (% waking time)	5.62	5.92	0.78	-	-
6. Person-mean MVPA (%)	5.42	3.72	-	-	-
7. Daily bodily pain (scale range = 1-4)	1.24	0.47	0.87	1	4
8. Daily fatigue (scale range = 1-4)	1.59	0.71	0.87	1	4
9. Typical physical health (scale range = 0-100)	80.95	17.59	-	21.67	100
10. Typical PA	140.57	58.11	-	43.21	330
11. Typical SB (min/day)	470.37	216.20	-	570	8,340
11. Typical pain (scale range = 1-5.5)	1.79	0.83	-	1	4.50
12. Typical fatigue (scale range = 20-100)	39.21	13.57	-	20	81
14. BMI (kg/m^2)	25.14	3.44	-	-	-
15. Age (years)	70.98	6.87	-	-	-

586

587   *Note.* Unstandardized estimates were used to calculate descriptive statistics.

Table 3

Multilevel Modelling Coefficients of Light PA and MVPA Predicting Daily Pain and Fatigue

Predictor Variable	Parameter Estimate (SE)	
	Model 1 bodily pain	Model 2 fatigue
Fixed Effects	β (SE)	β (SE)
Intercept	-0.136 (0.285)	-0.437 (0.309)
Daily light PA	0.151** (0.058)	0.029 (0.061)
Person-mean light PA	-0.064 (0.136)	0.080 (0.144)
Daily MVPA	0.110* (0.048)	0.044 (0.053)
Person-mean MVPA	-0.202 (0.156)	-0.005 (0.171)
Daily light PA x typical bodily pain	0.100 (0.075)	-
Daily MVPA x typical bodily pain	-0.090 (0.051)	-
Daily light PA x typical fatigue	-	-0.240** (0.072)
Daily MVPA x typical fatigue	-	-0.254*** (0.061)
Daily light PA x typical physical health	-0.014 (0.074)	-0.154 (0.084)
Daily MVPA x typical physical health	-0.030 (0.058)	-0.164* (0.076)
Typical PA	0.012 (0.083)	-0.122 (0.091)
Typical pain	0.543*** (0.113)	-
Typical fatigue	-	0.263* (0.119)
Typical physical health	-0.070 (0.105)	0.006 (0.131)
BMI	-0.097 (0.089)	0.151 (0.097)
Age	-0.155 (0.102)	0.132 (0.113)
Cardiovascular disease	0.040 (0.178)	0.483* (0.190)
Gender	0.063 (0.240)	0.308 (0.248)
Cohabiting	0.139 (0.193)	-0.076 (0.211)
Random Effects		

Intercept	0.283*** (0.079)	0.369*** (0.093)
Residual (AR1 diagonal)	0.434*** (0.041)	0.492*** (0.043)
-2 restricted log likelihood	798. 796	857.948
Akaike information criterion	804.796	863.948
$R_1{}^2$	0.528	0.210

590

591   *Note. *$p < .05$, ** $p < .01$, *** $p < .000$.*

592   Table 4

593   *Multilevel Modelling Coefficients of SB Predicting Daily Pain and Fatigue*

Predictor Variable	Parameter Estimate (SE)	
Fixed Effects	Model 3 bodily pain	Model 4 fatigue
	β (SE)	β (SE)
Intercept	-0.121 (0.281)	-0.373 (0.315)
Daily SB	-0.182** (0.061)	-0.050 (0.065)
Person-mean SB	0.171 (0.130)	-0.047 (0.143)
Daily SB x typical bodily pain	-0.015 (0.076)	-
Daily SB x typical fatigue	-	0.336*** (0.080)
Daily SB x typical physical health	0.052 (0.077)	0.212* (0.096)
Typical sedentary time	-0.102 (0.086)	-0.035 (0.096)
Typical pain	0.515*** (0.109)	-
Typical fatigue	-	0.274* (0.120)
Typical physical health	-0.063 (0.102)	0.009 (0.133)
BMI	-0.064 (0.084)	0.142 (0.094)
Age	-0.128 (0.095)	0.136 (0.107)
Cardiovascular disease	0.029 (0.174)	0.489* (0.191)
Gender	0.110 (0.229)	0.299 (0.246)
Cohabiting	0.083 (0.196)	-0.174 (0.221)
Random Effects		
Intercept	0.271*** (0.075)	0.378*** (0.093)
Residual (AR1 diagonal)	0.436*** (0.040)	0.494*** (0.043)
-2 restricted log likelihood	789.974	850.538
Akaike information criterion	795.974	856.538
R_1^2	0.548	0.191

594   *Note.* $*p < .05$, $** p < .01$, $*** p < .0$

31