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1   **ABSTRACT**

2   **Background:** Sedentary behaviour (SB) is negatively associated with cognition and mood.

3   Adults often engage in high levels of SB at work through sitting, which may impact

4   productivity. Consequently, replacing sitting with standing and physical activity (PA) is

5   recommended. However, the associations between sitting, standing and PA at work, and

6   cognition and mood are unknown, this study therefore aimed to explore these relationships.

7   **Methods:** Seventy-five healthy, full-time workers (33 male, [mean±SD] 33.6±10.4 years, 38±7

8   work hours/week) wore SB (activPAL) and PA (SenseWear Pro) monitors for seven days and

9   recorded their work hours. The day after this monitoring period, participants completed

10   cognitive tests (executive function, attention and working memory) and mood questionnaires

11   (affect, alert, content and calm). Multiple linear regression analyses examined the associations

12   between cognition and mood and the time spent sitting, standing and in each PA intensity during

13   work hours, weekday leisure time and weekends. **Results:** Workplace sitting, standing or PA

14   was not significantly associated with cognition or mood (p>0.05). No significant associations

15   were observed between these variables during weekday leisure time or weekends (p>0.05).

16   **Conclusions:** In a cohort of healthy workers, workplace sitting, standing and PA are not

17   associated with cognition or mood. Further research in this population is needed examining the

18   influence of workplace behaviours on cognition and mood, as this will contribute to evidence-

19   based workplace guidelines to increase productivity.

20 **INTRODUCTION**

21 The importance of workplace physical inactivity was first demonstrated with the observation

22 that active bus conductors had lower cardiovascular disease incidence compared to 'inactive',

23 or as they would now be classified, sedentary, bus drivers.[1] The workplace has since been

24 identified as a key setting where adults accrue high amounts of sedentary behaviour (SB),

25 defined as any waking behaviour in a sitting, reclining or lying posture.[2] Office workers

26 spend 65–75% of their work hours sitting, typically in prolonged bouts.[3–5] Importantly, a

27 significant proportion of an adults' week is spent at work, thus exposing workers to high levels

28 of sitting. This is clinically relevant since SB is recognised as an independent risk factor for

29 physical and mental health conditions.[6,7] Considering this, recent guidelines suggest replacing

30 workplace sitting with two hours of standing and light-intensity physical activity (PA) could

31 improve employee health and wellbeing, as well as their productivity.[5] However, there is little

32 evidence to support these recommendations.[8,9]

33

34 Cognition is related to work performance due to its influence on workers' ability to learn and

35 execute the skills needed to carry out tasks, and has been established as one of the best

36 predictors of work performance across a range of professions.[10] Indeed, cognitive ability is

37 negatively associated with counterproductive work behaviours[11] and employees with greater

38 cognitive capabilities perform more work tasks.[12] Pertinently, associations between cognition

39 and SB have been observed. Cross-sectional and prospective studies in older adults indicate

40 that SB is negatively associated with cognition.[13–15] However, such research excludes the

41 working-age population (18-60 years), an important and potential at risk cohort since some

42 aspects of cognitive performance start declining from the age of 20 years.[16] Indeed, minimal

43 research has explored the impact of SB at work on cognition. Furthermore, a systematic review

44 found inconclusive results from the few studies (n=13) examining interventions to reduce

45 workplace SB and improve cognition.[17]

46

47 Mood has also been shown to influence work productivity,[18,19] with workers in a positive mood

48 demonstrating more efficiency and effectiveness in their job roles.[20,21] Furthermore, positive

49 affect is positively related to task performance and negatively related to counterproductive work

50 behaviours, with opposite associations observed for negative affect. [18,19] Mood decreases

51 following up to two weeks of experimentally increasing free-living SB. [22,23] Furthermore, using

52 ecological momentary assessment analyses which allows for real-time assessment during

53 everyday life, time spent in SB was negatively associated with valence and energised arousal.[24]

54 However, whether SB accrued specifically during work hours contributes to these mood

55 disturbances is unknown.

56

57 Guidelines to reduce sitting in the workplace recommend progressing towards two hours of

58 standing and light-intensity PA during working hours to improve employee productivity.[5]

59 However, the recommendation of light-intensity PA and standing is based on previous research

60 showing improved blood glucose and insulin concentrations when breaking up prolonged

61 sitting.[25–27] Consequently, whether increasing the time spent in these behaviours can have

62 beneficial effects on factors influencing work productivity, such as cognition and mood, is

63 unknown. Accordingly, this study firstly assessed the relationship between cognition, mood and

64 objectively measured time spent sitting, stepping or standing and in light-, moderate-, and

65 vigorous-intensity PA whilst at work, as well as during weekday leisure time and weekends.

66 Secondly, based on current workplace guidelines,[5] this study assessed whether there was a

67 difference in cognition and mood between individuals who already accumulate two hours of

68 standing and light-intensity PA during their working hours and those who do not. It was

69 hypothesised that greater time spent sitting at work would be associated with lower cognition

70 and mood. Based on current workplace guidelines,[5] it was also hypothesised that standing and

71 light-intensity PA at work would be positively associated with cognition and mood and that

72 those already meeting these guidelines would have higher cognition and mood scores compared

73 to those who do not.

74

75 **METHODS**

76 **Participants**

77 Eighty-four healthy, full-time workers (37 male) volunteered and provided written informed

78 consent prior to commencing the study. Participants were recruited via convenience sample,

79 using advertising emails and posters that were distributed via local business mailing lists.

80 Recruitment and testing took place across a one-year period (November 2016 – November

81 2017). In order to capture a variation of workplace activity levels (i.e. both those who had high

82 and low sitting time), participants from any workplace were eligible to participate, providing

83 they were employed full-time (minimum of 35 hrs per week). Participants were screened for

84 exclusion criteria including: part-time employment (<35 hrs per week), use of medication,

85 current smoker, body mass index >35 or <18 $kg \cdot m^{-2}$ and diagnosis of cerebrovascular,

86 cardiovascular or metabolic disease. Study procedures were approved by the Liverpool John

87 Moores University Ethics Committee and adhered to the Declaration of Helsinki.

88

89 **Study design and procedures**

90 Data collection occurred either at Liverpool John Moores University or at the participants'

91 workplace in a private, quiet room without any external disturbances. Participants completed

92 two test visits. During visit one, participants were fitted with two activity monitors, the

93 activPAL3 and SenseWear Pro to measure SB and PA respectively, and given a wear-time

94 logbook to complete. Following this, participants wore the monitors for the next seven

95 consecutive days and were instructed to maintain their habitual workplace and leisure time

96 behaviours. The second visit occurred between 7.00-9.00 am the day after participants finished

97 wearing the monitors. The time of this visit was selected to prevent daily events potentially

98 influencing participants' cognition and mood. Participants were also instructed to maintain their

99 normal sleep patterns, and diet and caffeine consumption so that the monitoring period

100 represented a typical week for them. Furthermore, this visit always took place the day after a

101 workday (Tuesday-Friday) to ensure that the effects of a weekend, where participants'

102 behaviours may be different to a workday, did not influence cognition and mood outcomes.

103 During this visit participants completed a battery of computer-based cognitive performance

104 tests and two mood questionnaires.

105

106 **Measurements**

107 *Sedentary Behaviour.* SB was assessed using the activPAL3 monitor (PAL Technologies,

108 Glasgow, UK), a valid and reliable measure of sedentary time.[28] The activPAL contains a tri-

109 axial accelerometer which responds to gravitational acceleration and acceleration due to

110 segmental movement, enabling the time spent lying, sitting, standing and stepping to be

111 determined.[28,29] For each participant, the activPAL was initialised at a sampling frequency of

112 20 Hz. The activPAL was waterproofed using a small flexible sleeve to cover the monitor and

113 then secured onto the anterior mid-line of their right upper thigh by the principal researcher

114 using a waterproof medical grade adhesive dressing (Tegaderm). Waterproofing the device

115 permitted participants to wear the monitor continuously for the entire assessment period, which

116 can increase wear time compliance.[30] Additional waterproof dressings and attachment

117 instructions were given to participants in case the monitor became detached during the

118 assessment period to allow for reattachment, or they were advised to contact the principal

119   researcher. Participants were instructed to wear the activPAL monitor continuously over five

120   weekdays and two weekend days (i.e. Saturday and Sunday); as recommended for valid data.[30]

121   Data were downloaded from the monitor using activPAL software (version 7.2.32) and saved

122   in 15 second epochs across 24-hour periods. Data for a day was considered invalid if the monitor

123   was worn < 10 hours, had < 500 steps recorded or any one activity accounted for ≥ 95% of

124   waking wear time.[31] Further validation of data took place by visually inspecting the activPAL

125   event file outputs to corroborate if self-report wake-up and bedtime corresponded with

126   activPAL data. When assessing working hours, it was required that the monitor was worn for

127   >90% of work time. Data were then exported into Excel (Microsoft) for analyses, details of

128   which are provided in Supplementary File 1.

129

130   ***Physical Activity.*** PA was assessed using the SenseWear Pro 3 (BodyMedia, Inc., Pittsburgh,

131   PA, USA), a multisensory body monitor that is a valid method to assess energy expenditure and

132   in turn PA.[32] Each armband was initialised based on participants' stature, body weight, sex and

133   age. Participants then wore the armband around the upper right arm, in accordance with

134   manufacturer guidelines. Participants were instructed to wear the armband continuously for

135   seven days, only removing for showering or other water-based activities. Data were

136   downloaded from the armband and analysed using SenseWear professional software (version

137   7.0, BodyMedia, Inc.), which uses algorithms developed by the manufacturer to determine

138   MET values for one minute epochs. For each day, data were considered valid if the monitor

139   was worn ≥10 hours per day and if wear time corresponded with the participant's self-report

140   wear time diary. Based on this criteria, a participant's data were used in analyses if three

141   weekdays and two weekend days were considered valid.[33] These data were then exported to

142   Excel and separated into weekdays and weekends as described in Supplementary File 1. For

143   each day, the time spent in different categories of PA was determined based on recognised

144   METs values: light-intensity PA 1.5-3.0 METs, moderate-intensity PA 3.1-6.0 METs, and

145   vigorous-intensity PA >6.0 METs.[34] The time spent in moderate-to-vigorous PA (MVPA) was

146   determined by summing the time engaged in moderate- and vigorous-PA. Minute-by-minute

147   data for each category were summed to determine the total time spent in each intensity per day

148   for waking hours and these values were then summed to calculate total PA per day.

149

150   *Activity Monitoring Analysis.* During the activity monitoring period, to delineate between work

151   hours and leisure time activities, participants were given a logbook to record the time they

152   started and finished work each day, as is standard practise.[30] Additionally, participants recorded

153   the time they woke up and went to bed each day to allow for only waking hours to be included

154   in analyses. Participants were provided with written and verbal instructions regarding how to

155   wear the activity monitors and use the logbook. Data from the monitors were only included if

156   both SB and PA data were valid for the same day (i.e. if the participant only wore one of the

157   monitors this day was excluded). For each day, the time spent sitting, standing and stepping and

158   in each intensity of PA were calculated for waking hours, defined using the participants'

159   logbook, and expressed as a percentage of waking hours. Mean values were then determined

160   for each variable to represent a weekday and a weekend day. The same variables were then

161   calculated for work hours, defined using participants' self-report working hours, and expressed

162   as a percentage of total work hours. Total values for the week were calculated using a weighted

163   mean to account for the disproportionate time spent in weekdays compared to weekend days

164   across a week (weekday x 0.71 + weekend x 0.29). Variables for leisure time during the

165   weekday were calculated by subtracting work hours data from weekday data, therefore

166   removing any activity during the time spent at work. *Cognition.* All tests were conducted using

167   E-Prime software (Version 2.0 Professional, Psychology Software Tools, Pittsburgh, PA). The

168   E-Prime software was loaded onto a computer and participants completed the tests while seated

169   in a silent room, therefore there were no audible or visual distractions during testing. The

170   cognitive test battery assessed three cognitive components, using three separate tests, with a

171   break permitted between tests. Prior to each test, participants were provided with written

172   on-screen instructions and given the opportunity to ask questions. Participants took

173   between 45-60 minutes to complete the test battery.

174   *Executive function* was assessed using the Stroop Colour-Word test[35] which generated an

175   interference score based on the reaction times (RT) from three tasks: the Word Task, the Colour

176   Task and the Colour-Word Task. For each task, participants were instructed to name the ink

177   colour of the displayed text by pressing the keyboard letter that corresponded to that colour. In

178   the Word Task the words 'red', 'blue', 'yellow' or 'green' were presented in a congruous ink

179   colour. In the Colour Task a series of four letter X's were presented in either red, blue, yellow

180   or green ink. In the Colour-Word Task the names of these four colours were presented in an

181   incongruent ink colour. For each task, the percentage of correct responses was determined and

182   the mean RT for correct responses calculated. An interference score was calculated by

183   subtracting the mean time needed to complete the Colour and Word tasks from the time needed

184   to complete the Colour-Word task (Interference = Colour-Word task – [(Word task + Colour

185   task) / 2].[36]

186   *Attention* was assessed using the Attention Network Task (ANT) which examined three

187   attentional networks: alerting, orienting and executive control.[37] A central arrow was displayed

188   on screen and participants were required to indicate the direction (left or right) of this arrow by

189   clicking with the computer mouse in the corresponding direction. The central arrow was flanked

190   by one of three types of flankers: two arrows each side pointing in the same direction as the

191   central arrow (congruent condition), two arrows each side pointing in the opposite direction of

192   the central arrow (incongruent condition), or two straight lines each side of the central arrow

193   (neutral condition). Prior to the presentation of the arrow, participants were shown one of four

194   cue (*) types: a central cue, a double cue, a spatial cue, or no cue. The central and double cues

195   indicated that the arrow would be presented soon, while the spatial cue additionally provided

196   an indication of where the arrow would be presented. The no cue provided none of this

197   information. The efficiency of these networks was assessed by determining how alerting cues,

198   spatial cues and flankers influenced RT to respond to the arrow. Mean RT for correct trials was

199   calculated as a function of a cue or flanker condition to form a RT score for each network.[37]

200   *Working memory* was assessed using the N-Back Task[38] which calculated the response accuracy

201   to identify whether a presented letter was the same as that presented one (one-back), two (two-

202   back) or three (three-back) times prior in a letter sequence. Typically, as the working memory

203   demand increases in each condition, so in turn does the number of errors. For all conditions a

204   series of letters were consecutively presented on the screen and participants had to respond

205   whether this letter was a target or a non-target. Participants logged their response by clicking

206   with the computer mouse either left for a target letter or right for a non-target letter.

207

208   *Mood.* Mood was assessed using two questionnaires: The Positive and Negative Affect

209   Schedule (PANAS)[39] and the Bond-Lader Mood Rating Scale.[40] The PANAS required

210   participants to respond using a 5-item Likert scale ranging from 1 (very slightly or not all all)

211   to 5 (extremely) the extent to which they felt 10 positive and 10 negative states. Values were

212   then totalled to give separate positive and negative affect scores ranging from 10-50. The Bond-

213   Lader Mood Rating Scale included 12 visual analogue scales featuring bipolar end-points for

214   different mood dimensions: Alert-Drowsy, Calm-Excited, Strong-Feeble, Clear Headed-

215   Muzzy, Well Coordinated-Clumsy, Energetic-Lethargic, Contented-Discontented, Tranquil-

216   Troubled, Quick Witted-Mentally Slow, Relaxed-Tense, Attentive-Dreamy, Proficient-

217   Incompetent, Happy-Sad, Amicable-Antagonistic, Interested-Bored, and Gregarious-

218   Withdrawn. These scales were combined to form three mood factors: alert, calm and content;

219   with each mood factor calculated as an average of the scores from the relevant mood scales.[40]

220   For both questionnaires, participants were asked to respond based on their mood over the past

221   few days.

222

223   **Statistical analyses**

224   Data were analysed using statistical software (SPSS Version 25.0, IBM Corporation, Somers,

225   NY, USA). Results are presented as means ± standard deviation (SD). Multiple linear regression

226   analysis was used to examine the independent associations between cognition and mood and

227   the time spent sitting, standing, stepping and in each PA intensity during work hours, weekday

228   leisure time and weekends. All models run were adjusted for age and sex. Cognition and mood

229   data were standardised using z-scores transformations. Linear transformations of 5% were

230   applied to sitting, standing, stepping and PA data to adjust the interpretation of coefficients

231   from a 1% to 5% change in each domain. Results of the multiple linear regression analyses are

232   presented as the unstandardised coefficient with 95% confidence intervals (CI). P-values were

233   adjusted for multiple comparisons using a false discovery rate (FDR). To assess for differences

234   in cognition and mood based on meeting current workplace activity guidelines, data were split

235   into two groups: individuals who accumulated two hours of standing and light-intensity PA

236   during their working hours, and those who did not. Differences between groups were assessed

237   using a one-way ANCOVA, with age and sex as covariates. Significance was accepted as

238    $p < 0.05$.

239

240   **RESULTS**

241   From the originally recruited sample size of 84, 75 participants (33 male) completed the study

242   and were included in analyses. Nine participants were excluded due to invalid activity monitor

243   wear time. Participants were a mean age of 33.6±10.4 years, with a body mass of 71.8±14.2 kg,

244 stature of 169.3±9.4 cm and a body mass index of 25.0±3.8 kg·m^{-2}. Full descriptive

245 characteristics are shown in Table 1. Participants were employed across 12 different

246 workplaces, representing nine sectors. Mean time spent sitting, standing, stepping and in each

247 PA intensity during work hours, weekday leisure time, weekends and per week are shown in

248 Table 2. Mean scores for all cognition and mood outcomes are shown in Supplementary Table

249 1.

250 **Sitting, standing and stepping**

251 Multiple linear regression analyses between the time spent sitting, standing and stepping in each

252 domain (work hours, weekday leisure time and weekends) and all cognition outcomes are

253 shown in Table 3 and all mood outcomes are shown in Table 4. Weekday leisure time sitting

254 was positively associated with executive control score (β=0.292, p=0.033), indicating longer

255 RTs with increased time spent sitting. Negative associations were observed between weekday

256 leisure standing and one back accuracy (β=-0.289, p=0.040) and work hours standing and three

257 back accuracy (β=-0.290, p= 0.021). Stepping during weekday leisure time was positively

258 associated with orienting network score (β=0.303, p=0.024), indicating longer RTs with

259 increased time spent stepping, and with the calm mood state (β=0.292, p=0.046). All significant

260 outcomes returned to the null once FDR corrections were applied (p>0.05).

261

262 **Physical activity intensity**

263 Multiple linear regression analyses between the time spent sitting, standing and stepping in each

264 domain (work hours, weekday leisure time and weekends) and all cognition outcomes are

265 shown in Table 5 and all mood outcomes are shown in Table 6. Negative associations were

266 observed between work hours moderate-intensity PA (β=-0.310, p=0.042) and MVPA (β=-

267 0.317, p=0.037) and executive function, indicating shorter RTs with increased time spent in

268 these intensities of PA. Work hours moderate-intensity PA (β=0.327, p=0.044) and MVPA

11

269   (β=0.319, p=0.049) were positively associated with the content mood state. Negative

270   associations were also observed between weekday leisure time moderate-intensity PA (β=-

271   0.341, p=0.024) and MVPA (β=-0.335, p=0.03) and executive control score, indicating shorter

272   RTs with increased time spent in these intensities of PA. Weekday leisure time moderate-

273   intensity PA (β=0.352, p=0.027) and MVPA (β=0.373, p=0.024) were positively associated

274   with the calm mood state. Weekend vigorous-intensity PA was positively associated with the

275   alert mood state (β=0.322, p=0.049). All significant outcomes returned to the null once FDR

276   corrections were applied (p>0.05).

277

278   **Workplace guidelines**

279   Fifty-five participants (73.3%) achieved the current workplace guidelines of at least two hours

280   of standing or light-intensity PA during work hours; whilst twenty participants (26.7%) did not.

281   Mean scores for all cognition and mood outcomes for each group are shown in Table 7. No

282   significant differences were observed for any cognition or mood outcomes between the groups

283   (p>0.05).

284

285   **DISCUSSION**

286   This study assessed whether sitting at work is associated with cognition and mood. A less

287   sedentary workplace has been suggested to be more productive,[5] and cognition and mood likely

288   play a role in employee productivity. In contrast to this, we found no independent association

289   between the time spent sitting at work and aspects of cognition and mood once controls for

290   multiple comparisons were applied. Additionally, we found that neither standing nor any

291   intensity of PA during work hours were associated with cognition or mood. Furthermore, this

292   study explored whether cognition and mood differed between individuals who accumulate two

293   hours of standing and light-intensity PA during their working hours, in line with current

294   guidelines,[5] and those who do not. However, no differences between groups were observed for

295   any cognition or mood outcomes. Collectively these findings suggest that further research is

296   needed to explore the impact of workplace sitting and PA on aspects of cognition and mood in

297   healthy, working-age adults. Together, this information will contribute to evidence-based

298   guidelines on workplace behaviours to increase productivity.

299

300   The finding that sitting at work was not associated with cognition contrasts previous research

301   showing relationships between SB and cognition.[13–15] However, these previous studies have

302   assessed older populations who experience an accelerated rate of age-related cognitive decline

303   compared to younger adults,[16] and in this study we have assessed young, working-age adults,

304   with a mean age of 33 years. Consequently, this may indicate sitting has minimal impact on

305   cognition for younger adults. Indeed, experimental studies assessing young, healthy adults have

306   observed no impairment in cognition following an acute prolonged sitting period[41,42] or

307   following a one-week free-living SB intervention.[43] Additionally, it has been suggested that

308   participants' regular PA may offset the effects of sitting on cognition.[17] Indeed, in adults that

309   met PA guidelines, one-week of experimentally increased free-living SB did not negatively

310   affect mood.[43] Furthermore, the cognitive engagement of the activities that participants engage

311   in whilst at work, in addition to their PA and SB levels, may impact cognition.[17] Such factors

312   were not assessed or controlled for in this study, which may contribute to our findings.

313

314   The time spent sitting at work was not associated with aspects of mood, which contrasts

315   previous research showing negative associations between sitting and valence and energised

316   arousal.[24] However, this previous work used ecological momentary assessment analyses, which

317   allowed for the real-time assessment of mood directly following a prolonged sitting period. In

318   our study, we asked participants to recall their mood over the past few days, consequently,

319 alongside recall bias, a combination of daily events over this time period may have altered mood

320 state above that which sitting could influence. Indeed, mood is known to transiently change

321 throughout the day owing to daily stressors[44] and responses can persist for hours following an

322 event.[45] Consequently, to fully understand the influence of work hours sitting on mood,

323 assessments of mood should be determined at the start and immediately at the end of a working

324 day; which future research should consider.

325

326 In addition to workplace sitting, this study also assessed whether the time spent standing and

327 engaging in any intensity of PA were associated with cognition and mood. Importantly, we

328 found no associations between the time spent in any of these behaviours and mood or cognition.

329 These findings support previous research stating inconclusive results from studies examining

330 the effect on cognition of PA interventions to reduce workplace sitting time.[17] Furthermore, no

331 differences in cognition were observed between individuals who attained current workplace

332 guidelines of two hours of standing and light-intensity PA[5] and those that did not. Taken

333 together, this may indicate that PA during work hours is not sufficient to alter cognition and

334 longitudinal studies are needed to explore this further. Collectively, our data does not align with

335 current workplace activity guidelines[5] and may indicate that recommending standing and light-

336 intensity PA will not elicit improvements in workers' mood and cognition, and their subsequent

337 productivity. Furthermore, our findings support previous criticisms regarding the lack of

338 evidence to support these recommendations.[8,9] This indicates that more research is required in

339 the area of workplace activity before guidelines regarding the duration and type of PA can be

340 prescribed.

341

342 In addition to the workplace, this study examined the time spent sitting, standing, stepping and

343 in each PA intensity during weekday leisure time and weekends to explore if results differed

344   depending on the domain assessed. As observed for work hours, in each of these domains, the

345   time spent engaging in any of these behaviours was not significantly associated with cognition

346   and mood. The lack of association between mood and PA may be surprising owing to the

347   frequently cited benefits of PA on mood state.[46] However, the effect of PA on mood is

348   attenuated when individuals' mood scores are higher.[47] Consequently, in our sample of healthy

349   adults, the association between PA and mood may be small owing to their higher overall mood.

350   Furthermore, the duration and modality of PA are factors that can influence mood[46] and we

351   were not able to explore the type of PA nor the duration of the PA bouts that individuals

352   completed. The lack of association between PA and cognition may be surprising given the

353   benefits of PA for the maintenance of cognition.[48,49] However, the majority of research in this

354   area has examined children and older adults, with little focus on young and middle-age adults,[49]

355   which is the age range included in this study. Thus, whether PA is associated with cognition in

356   young and middle-aged healthy adults is less clear.

357

358   *Limitations.* This study is strengthened by the objective assessment of sitting, standing, stepping

359   and PA over an entire week which provided a complete picture of our participants' habitual

360   activity levels across various time domains. Nonetheless, we only assessed a small number of

361   cognitive domains and mood states that could influence workers' productivity; others may be

362   associated with sitting and PA and should be explored. For example, The National Institutes of

363   Health have identified executive function, episodic memory, language, processing speed,

364   working memory, and attention as the cognition subdomains most important for health and

365   success in work;[50] all of which were not assessed in our study. Additionally, we did not control

366   for factors such as sleep, stress, caffeine and diet, which are important determinants of cognition

367   and mood. Furthermore, the weekday on which cognition and mood assessments took place

368   was not controlled between individuals, and changes in mood across the week are suggested.[51]

369 The influence of the number or the length of breaks from sitting on cognition and mood were

370 not considered, factors which are known to have an important effect on cardiometabolic health

371 markers.[52] Some participants were employed in the same workplace which may increase the

372 homogeneity of our data, owing to similar work hour behaviour patterns. Nonetheless, our

373 sample appears representative of the typical English workers since weekday sitting (61.0%),

374 standing (26.1%) and stepping (13.0%) time was similar to that previously reported by Smith

375 et al.[53] in English workers (weekday sitting 66.2%, standing 23.3% and stepping 10.5%).

376 Finally, whilst our study found no significant associations between workplace activity and

377 cognition and mood, fully powered studies are needed to confirm or refute these findings.

378

379 **CONCLUSION**

380 This study demonstrates that in young, healthy workers, sitting during work hours is not

381 associated with cognition or mood, factors that can influence work productivity. In contrast to

382 guidelines advising increasing standing and light-intensity PA at work to improve productivity,

383 these behaviours were not associated with cognition or mood. Additionally, meeting the

384 recommendation of two hours of standing and light-intensity PA during working hours did not

385 result in higher levels of cognition or mood. Further research is therefore needed to determine

386 the influence of workplace sitting and PA on cognition and mood to provide evidence-based

387 guidelines on workplace behaviours to increase productivity. Additionally, the influence of

388 sitting during work hours on other domains of cognition and mood and over a long-term follow

389 up should be explored.

396 **AUTHOR CONTRIBUTIONS**

397 SC, NH, DT, and RD contributed to the conception and design of the study.

398 SC completed all data collection and analyses. SC and AT statistically analysed data. SC and

399 AT interpreted the data. SC drafted the initial manuscript. All authors contributed to the critical

400 revision of the manuscript, approve the final submission and take responsibility for the integrity

401 of the data and the accuracy of the data analysis.

402

403 **COMPETING INTERESTS**

404 RD is employed by Unilever, which has commercial interests in Food, Home and Personal Care

405 products. All other authors declare that they have no competing interests.

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567

List of Tables

Table 1: Participant descriptive characteristics (n=75, 33 male)

	Mean±SD or n of group
Age (years)	33.6±10.4
Body Mass (kg)	71.8±14.2
Stature (cm)	169.3±9.4
Body Mass Index (kg·m^{-2})	25.0±3.8
Ethnic Group	
White British	69
Asian	5
Caribbean or Black	1
Marital Status	
Single	45
Married	29
Divorced	1
Tertiary Level of Education	75
Job Category	
Administration	22
Research and Development	21
Education	8
Managerial	6
Computing	5
Human Resources	4
Commercial	4
Legal/Finance	3
Sport/Leisure	2
Work Hours (per week)	38±7
Work Hours (per day)	8±1

Table 2: Time spent engaging in objectively measured sitting, standing, stepping and physical activity (PA) intensities during work hours, weekday leisure time, weekends and per week (n=75, mean±SD).

	Time	% of Waking Wear Time
Work Hours		
Sitting Time (minutes)	322.9±86.0	66.2±14.4
Standing Time (minutes)	115.9±62.5	22.9±10.9
Stepping Time (minutes)	54.7±36.6	10.9±6.5
Light-Intensity PA (minutes)	142.2±59.3	28.7±10.9
Moderate-Intensity PA (minutes)	40.9±35.2	8.2±6.3
Vigorous-Intensity PA (minutes)	1.8±3.5	0.4±0.7
MVPA (minutes)	42.7±36.0	8.6±6.4
Total PA (minutes)	184.9±80.0	37.3±13.9
Weekday Leisure Time		
Sitting Time (minutes)	262.0±75.1	55.8±10.9
Standing Time (minutes)	135.8±43.6	29.2±8.1
Stepping Time (minutes)	69.9±26.9	15.0±5.1
Light-Intensity PA (minutes)	146.4±58.2	34.3±10.1
Moderate-Intensity PA (minutes)	53.7±33.3	12.9±7.6
Vigorous-Intensity PA (minutes)	8.0±9.2	1.9±2.3
MVPA (minutes)	61.7±37.6	14.8±8.6
Total PA (minutes)	208.1±72.0	49.1±12.4
Weekends		
Sitting Time (minutes)	500.8±125.3	56.2±14.5
Standing Time (minutes)	272.6±99.9	30.2±10.6
Stepping Time (minutes)	123.1±54.1	13.6±5.5
Light-Intensity PA (minutes)	304.2±106.3	36.7±11.8
Moderate-Intensity PA (minutes)	90.0±66.0	11.0±8.2
Vigorous-Intensity PA (minutes)	8.0±13.9	0.9±1.6
MVPA (minutes)	98.0±72.9	11.9±8.9
Total PA (minutes)	402.2±132.9	48.6±14.2
Whole Week		
Sitting Time (minutes)	556.2±88.3	59.7±9.4
Standing Time (minutes)	255.6±72.5	27.2±7.1
Stepping Time (minutes)	123.7±43.0	13.2±4.3
Light-Intensity PA (minutes)	283.0±87.4	32.8±8.0
Moderate-Intensity PA (minutes)	90.3±54.4	10.5±6.1
Vigorous-Intensity PA (minutes)	9.0±10.0	1.0±1.1
MVPA (minutes)	99.3±59.5	11.5±6.5
Total PA (minutes)	387.5±108.6	44.4±10.7

PA- physical activity; MVPA- moderate-to-vigorous physical activity.

Table 3: Associations between executive function, attention and working memory (z-score) and the time spent sitting, standing and stepping during work hours, weekday leisure time and weekends.

	Cognition (z-scores)												
	Executive Function		Alerting Network		Orienting Network		Executive Control		One-Back		Two-Back		Three-Back	
	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*
Sitting													
Work Hours	0.061 (-0.026, 0.147)	0.165	0.053 (-0.032, 0.137)	0.217	-0.026 (-0.114, 0.062)	0.553	-0.035 (-0.121, 0.051)	0.418	-0.003 (-0.089, 0.083)	0.938	-0.004 (-0.093, 0.084)	0.921	0.082 (-0.006, 0.169)	0.066
Weekday Leisure	-0.053 (-0.176, 0.070)	0.395	-0.062 (-0.182, 0.059)	0.311	-0.092 (-0.217, 0.034)	0.149	0.134 (0.011, 0.256)	0.033	0.110 (-0.015, 0.234)	0.083	-0.001 (-0.128, 0.126)	0.987	-0.053 (-0.178, 0.073)	0.407
Weekend	0.041 (-0.051, 0.133)	0.380	0.012 (-0.078, 0.102)	0.796	0.040 (-0.053, 0.134)	0.393	-0.004 (-0.096, 0.087)	0.923	-0.056 (-0.148, 0.036)	0.226	0.020 (-0.074, 0.114)	0.669	-0.001 (-0.094, 0.093)	0.991
Standing													
Work Hours	-0.108 (-0.221, 0.005)	0.061	-0.092 (-0.204, 0.020)	0.107	-0.007 (-0.126, 0.112)	0.911	0.069 (-0.046, 0.184)	0.233	0.008 (-0.106, 0.121)	0.895	0.006 (-0.112, 0.124)	0.922	-0.136 (-0.251, -0.022)	0.021
Weekday Leisure	0.099 (-0.071, 0.268)	0.248	0.065 (-0.103, 0.232)	0.445	0.054 (-0.125, 0.232)	0.550	-0.159 (-0.331, 0.014)	0.070	-0.179 (-0.350, -0.008)	0.040	0.011 (-0.166, 0.189)	0.900	0.052 (-0.121, 0.225)	0.551
Weekend	-0.085 (-0.212, 0.042)	0.185	-0.022 (-0.148, 0.103)	0.724	-0.042 (-0.175, 0.092)	0.535	0.009 (-0.120, 0.138)	0.887	0.107 (-0.021, 0.234)	0.099	-0.022 (-0.155, 0.110)	0.740	0.018 (-0.111, 0.147)	0.785
Stepping													
Work Hours	-0.009 (-0.208, 0.190)	0.931	-0.019 (-0.210, 0.173)	0.847	0.141 (-0.049, 0.331)	0.142	0.011 (-0.185, 0.207)	0.910	0.017 (-0.181, 0.216)	0.861	0.013 (-0.186, 0.212)	0.896	-0.029 (-0.230, 0.173)	0.776
Weekday Leisure	0.036 (-0.240, 0.311)	0.797	0.146 (-0.119, 0.411)	0.276	0.304 (-0.042, 0.566)	0.024	-0.243 (-0.514, 0.029)	0.079	-0.087 (-0.364, 0.190)	0.532	-0.014 (-0.292, 0.263)	0.917	0.141 (-0.139, 0.422)	0.318
Weekend	0.016 (-0.234, 0.265)	0.901	0.011 (-0.230, 0.251)	0.929	-0.126 (-0.364, 0.112)	0.295	-0.011 (-0.257, 0.234)	0.926	0.017 (-0.233, 0.266)	0.893	-0.071 (-0.321, 0.179)	0.572	-0.052 (-0.305, 0.201)	0.683

*Statistical significance defined as false discovery rate (FDR) < 0.25.

Table 4: Associations between mood (z-score) and the time spent sitting, standing and stepping during work hours, weekday leisure time and weekends.

	Mood (z-scores)									
	Positive Affect		Negative Affect		Alert		Calm		Content	
	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*
Sitting										
Work Hours	-0.039 (-0.124, 0.047)	0.374	-0.007 (-0.096, 0.082)	0.878	-0.014 (-0.144, 0.087)	0.785	-0.049 (-0.141, 0.043)	0.286	-0.056 (-0.151, 0.038)	0.237
Weekday Leisure	0.003 (-0.119, 0.126)	0.957	-0.036 (-0.163, 0.091)	0.574	0.007 (-0.135, 0.150)	0.917	-0.099 (-0.229, 0.032)	0.136	-0.013 (-0.147, 0.122)	0.851
Weekend	-0.037 (-0.128, 0.055)	0.426	0.048 (-0.046, 0.143)	0.312	-0.038 (-0.152, 0.076)	0.508	0.025 (-0.080, 0.130)	0.637	-0.100 (-0.208, 0.008)	0.068
Standing										
Work Hours	0.029 (-0.086, 0.143)	0.621	0.045 (-0.073, 0.163)	0.448	-0.032 (-0.177, 0.113)	0.658	0.066 (-0.071, 0.202)	0.336	0.020 (-0.121, 0.160)	0.780
Weekday Leisure	-0.044 (-0.215, 0.128)	0.614	0.063 (-0.114, 0.239)	0.481	-0.028 (-0.224, 0.167)	0.773	0.073 (-0.111, 0.256)	0.428	-0.025 (-0.214, 0.164)	0.791
Weekend	0.065 (-0.063, 0.194)	0.315	-0.066 (-0.198, 0.066)	0.324	0.074 (-0.097, 0.244)	0.390	-0.033 (-0.193, 0.128)	0.685	0.162 (-0.002, 0.327)	0.053
Stepping										
Work Hours	0.108 (-0.085, 0.301)	0.269	-0.090 (-0.290, 0.110)	0.374	0.123 (-0.084, 0.330)	0.239	0.054 (-0.136, 0.243)	0.571	0.181 (-0.014, 0.377)	0.068
Weekday Leisure	0.070 (-0.197, 0.337)	0.602	0.029 (-0.248, 0.306)	0.837	0.025 (-0.298, 0.348)	0.877	0.301 (0.005, 0.596)	0.046	0.087 (-0.218, 0.392)	0.569
Weekend	0.020 (-0.222, 0.263)	0.867	-0.100 (-0.351, 0.152)	0.431	0.010 (-0.265, 0.285)	0.940	-0.039 (-0.290, 0.213)	0.758	0.150 (-0.110, 0.409)	0.251

*Statistical significance defined as false discovery rate (FDR) < 0.25.

Table 5: Associations between executive function, attention and working memory (z-score) and the time spent in each physical activity (PA) intensity during work hours, weekday leisure time and weekends.

	Cognition (z-scores)													
	Executive Function		Alerting Network		Orienting Network		Executive Control		One-Back		Two-Back		Three-Back	
	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*
Light-Intensity PA													
Work Hours	-0.088 (-0.199, 0.023)	0.117	0.00 (-0.116, 0.116)	1.000	-0.006 (-0.119, 0.107)	0.914	-0.007 (-0.101, 0.088)	0.891	0.079 (-0.036, 0.193)	0.174	0.069 (-0.045, 0.184)	0.231	0.015 (-0.088, 0.119)	0.768
Weekday Leisure	0.042 (-0.108, 0.193)	0.575	-0.060 (-0.218, 0.097)	0.445	0.002 (-0.151, 0.156)	0.976	0.000 (-0.128, 0.129)	0.999	-0.058 (-0.212, 0.096)	0.458	-0.050 (-0.205, 0.105)	0.522	-0.079 (-0.219, 0.060)	0.261
Weekend	-0.058 (-0.184, 0.067)	0.355	0.051 (-0.080, 0.182)	0.436	-0.062 (-0.190, 0.066)	0.336	0.021 (-0.086, 0.128)	0.691	0.075 (-0.054, 0.203)	0.249	-0.068 (-0.196, 0.061)	0.297	0.033 (-0.084, 0.642)	0.576
Moderate-Intensity PA													
Work Hours	-0.248 (-0.486, -0.009)	0.042	0.013 (-0.233, 0.260)	0.914	0.110 (-0.135, 0.355)	0.374	-0.027 (-0.216, 0.161)	0.774	-0.038 (-0.285, 0.210)	0.763	0.010 (-0.244, 0.264)	0.935	-0.128 (-0.350, 0.095)	0.256
Weekday Leisure	0.149 (-0.049, 0.347)	0.138	0.034 (-0.171, 0.239)	0.739	0.009 (-0.195, 0.212)	0.932	-0.181 (-0.338, -0.025)	0.024	0.021 (-0.185, 0.226)	0.842	0.048 (-0.163, 0.259)	0.650	0.111 (-0.074, 0.295)	0.237
Weekend	0.029 (-0.148, 0.206)	0.746	0.118 (-0.065, 0.301)	0.203	0.022 (-0.159, 0.204)	0.806	-0.032 (-0.172, 0.108)	0.651	0.126 (-0.058, 0.310)	0.175	0.028 (-0.161, 0.217)	0.767	0.016 (-0.149, 0.181)	0.848
Vigorous-Intensity PA													
Work Hours	-0.696 (-2.404, 1.013)	0.419	-0.120 (-1.860, 1.620)	0.891	-1.020 (-2.718, 0.678)	0.234	-0.067 (-1.475, 1.340)	0.924	-0.543 (-2.288, 1.203)	0.536	0.311 (-1.444, 2.066)	0.725	-1.075 (-2.593, 0.443)	0.162
Weekday Leisure	0.109 (-0.537, 0.755)	0.736	0.234 (-0.424, 0.892)	0.480	0.233 (-0.409, 0.875)	0.472	-0.205 (-0.737, 0.327)	0.444	0.233 (-0.428, 0.895)	0.483	0.103 (-0.562, 0.768)	0.758	0.515 (-0.060, 1.090)	0.078
Weekend	-0.104 (-0.963, 0.755)	0.809	-0.513 (-1.388, 0.362)	0.246	0.135 (-0.718, 0.989)	0.752	-0.263 (-0.970, 0.445)	0.461	-0.186 (-1.063, 0.692)	0.674	0.352 (-0.530, 1.235)	0.428	-0.410 (-1.173, 0.353)	0.287
MVPA													
Work Hours	-0.247 (-0.480, -0.015)	0.037	0.033 (-0.210, 0.275)	0.788	0.081 (-0.159, 0.320)	0.504	-0.027 (-0.211, 0.158)	0.772	-0.035 (-0.278, 0.207)	0.771	0.005 (-0.242, 0.253)	0.965	-0.150 (-0.365, 0.065)	0.167
Weekday Leisure	0.138 (-0.042, 0.318)	0.131	0.028 (-0.160, 0.217)	0.764	0.020 (-0.166, 0.205)	0.833	-0.158 (-0.301, -0.014)	0.031	0.026 (-0.162, 0.214)	0.784	0.049 (-0.143, 0.241)	0.608	0.133 (-0.034, 0.300)	0.117
Weekend	0.015 (-0.147, 0.177)	0.852	0.078 (-0.091, 0.248)	0.357	0.028 (-0.139, 0.195)	0.740	-0.031 (-0.159, 0.098)	0.634	0.098 (-0.071, 0.267)	0.250	0.033 (-0.140, 0.205)	0.705	-0.005 (-0.155, 0.145)	0.942

*Statistical significance defined as false discovery rate (FDR) < 0.25. PA- physical activity; MVPA- moderate-to-vigorous physical activity.

Table 6: Associations between mood (z-score) and the time spent in each physical activity (PA) intensity during work hours, weekday leisure time and weekends.

| | Mood (z-scores) | | | | | | | | | |
| | Positive Affect | | Negative Affect | | Alert | | Calm | | Content | |
	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*	Unstandardised coefficient (95% CI)	p-value*
Light-Intensity PA										
Work Hours	-0.028 (-0.143, 0.086)	0.622	-0.034 (-0.150, 0.083)	0.566	-0.037 (-0.163, 0.089)	0.558	-0.047 (-0.169, 0.075)	0.445	-0.018 (-0.146, 0.109)	0.772
Weekday Leisure	-0.050 (-0.205, 0.105)	0.521	0.001 (-0.157, 0.159)	0.989	0.039 (-0.134, 0.212)	0.651	-0.030 (-0.198, 0.138)	0.721	0.040 (-0.135, 0.215)	0.647
Weekend	-0.004 (-0.133, 0.125)	0.949	-0.022 (-0.153, 0.109)	0.739	-0.008 (-0.167, 0.150)	0.915	-0.083 (-0.236, 0.071)	0.283	0.044 (-0.116, 0.204)	0.583
Moderate-Intensity PA										
Work Hours	0.199 (-0.046, 0.443)	0.109	-0.120 (-0.363, 0.123)	0.328	0.148 (-0.100, 0.396)	0.235	0.087 (-0.143, 0.316)	0.450	0.238 (0.007, 0.469)	0.044
Weekday Leisure	0.001 (-0.202, 0.204)	0.994	0.064 (-0.138, 0.266)	0.530	0.010 (-0.208, 0.228)	0.925	0.229 (0.027, 0.431)	0.027	0.059 (-0.145, 0.262)	0.564
Weekend	-0.043 (-0.225, 0.139)	0.638	-0.152 (-0.333, 0.028)	0.097	0.051 (-0.137, 0.240)	0.587	0.019 (-0.156, 0.193)	0.831	0.084 (-0.091, 0.260)	0.339
Vigorous-Intensity PA										
Work Hours	0.130 (-1.612, 1.871)	0.882	-0.383 (-2.141, 1.375)	0.664	1.812 (-1.354, 4.977)	0.255	-0.534 (-3.853, 2.785)	0.747	0.962 (-2.355, 4.280)	0.562
Weekday Leisure	0.019 (-0.639, 0.678)	0.953	-0.092 (-0.756, 0.573)	0.784	-0.179 (-0.911, 0.554)	0.625	0.480 (-0.288, 1.247)	0.215	0.319 (-0.449, 1.086)	0.408
Weekend	0.137 (-0.738, 1.013)	0.755	-0.020 (-0.904, 0.864)	0.963	0.888 (0.004, 1.771)	0.049	-0.085 (-1.011, 0.842)	0.855	0.168 (-0.758, 1.095)	0.716
MVPA										
Work Hours	0.191 (-0.048, 0.430)	0.115	-0.113 (-0.333, 0.107)	0.310	0.138 (-0.103, 0.379)	0.256	0.073 (-0.152, 0.298)	0.518	0.226 (0.001, 0.452)	0.049
Weekday Leisure	-0.006 (-0.191, 0.179)	0.949	0.151 (-0.459, 0.762)	0.622	0.008 (-0.193, 0.209)	0.937	0.218 (0.031, 0.405)	0.024	0.067 (-0.121, 0.254)	0.478
Weekend	-0.029 (-0.195, 0.138)	0.731	-0.118 (-0.276, 0.041)	0.143	0.072 (-0.099, 0.243)	0.400	0.007 (-0.152, 0.167)	0.927	0.074 (-0.086, 0.234)	0.354

* Statistical significance defined as false discovery rate (FDR) < 0.25. PA- physical activity; MVPA- moderate-to-vigorous physical activity.

Table 7: Mean scores for all cognition (executive function, attention and working memory) and mood (positive and negative affect, alert, calm, content) outcomes split based on individuals who accumulated two hours of standing and light-intensity PA during their working hours (Achieved Guidelines, n=55) and those who did not (Did Not Achieve Guidelines, n=20) (mean±SD).

	Achieved Guidelines	Did Not Achieve Guidelines	p-value
Executive Function			
Interference Score (ms)	150±110	203±141	0.087
Attention			
Alerting Network (ms)	15±20	20±24	0.453
Orientating Network (ms)	17±23	13±22	0.593
Executive Control (ms)	68±35	68±24	0.957
Working Memory			
One Back Accuracy (%)	91.8±7.3	92.0±8.2	0.969
Two Back Accuracy (%)	90.4±10.3	84.0±22.1	0.099
Three Back Accuracy (%)	74.9±20.7	81.3±10.4	0.139
Mood			
Positive Affect	34.3±6.5	30.6±7.6	0.052
Negative Affect	16.2±5.7	15.6±5.4	0.667
Alert	68.0±16.6	61.4±16.6	0.237
Calm	52.1±11.5	48.1±14.0	0.283
Content	69.1±16.7	61.1±17.5	0.126