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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 behaviours¹¹ 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·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 $\geq 95\%$ 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 test³⁵ 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 Task³⁸ 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 \pm 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 $\text{kg} \cdot \text{m}^{-2}$. 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 ($\beta=0.292$, $p=0.033$), indicating longer
255 RTs with increased time spent sitting. Negative associations were observed between weekday
256 leisure standing and one back accuracy ($\beta=-0.289$, $p=0.040$) and work hours standing and three
257 back accuracy ($\beta=-0.290$, $p=0.021$). Stepping during weekday leisure time was positively
258 associated with orienting network score ($\beta=0.303$, $p=0.024$), indicating longer RTs with
259 increased time spent stepping, and with the calm mood state ($\beta=0.292$, $p=0.046$). 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 ($\beta=-0.310$, $p=0.042$) and MVPA ($\beta=-$
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 ($\beta=0.327$, $p=0.044$) and MVPA

269 ($\beta=0.319$, $p=0.049$) were positively associated with the content mood state. Negative
270 associations were also observed between weekday leisure time moderate-intensity PA ($\beta=-$
271 0.341 , $p=0.024$) and MVPA ($\beta=-0.335$, $p=0.03$) and executive control score, indicating shorter
272 RTs with increased time spent in these intensities of PA. Weekday leisure time moderate-
273 intensity PA ($\beta=0.352$, $p=0.027$) and MVPA ($\beta=0.373$, $p=0.024$) were positively associated
274 with the calm mood state. Weekend vigorous-intensity PA was positively associated with the
275 alert mood state ($\beta=0.322$, $p=0.049$). 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 stressors⁴⁴ 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 PA⁵ 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 guidelines⁵ 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 mood⁴⁶ 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.

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393 had no role in the design and conduct of the study; collection, management, analysis, and
394 interpretation of the data; and preparation, review, or approval of this manuscript.

395

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