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1 **Physical activity, sleep and symptoms of depression in adults –**
2 **testing for mediation**

3

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27 **ABSTRACT**

28 **Purpose** Physical activity, sleep problems and symptoms of depression contribute to overall
29 wellbeing. The factors are reciprocally associated, but the nature of these associations remains
30 unclear. The present study examined whether sleep problems mediated the association between
31 physical activity and depressive symptoms.

32 **Methods** The eligible population ($n = 3596$) consisted of adults from the ongoing, population-
33 based Cardiovascular Risk in Young Finns Study started in 1980. Participants' leisure-time physical
34 activity was assessed with physical activity index (2007) and sleep problems with Jenkins' Sleep
35 Questionnaire (JSQ) in 2007 and 2011. Depressive symptoms were measured using modified Beck
36 Depression Inventory (BDI-II) in 2007 and 2012, from which the items reflecting sleep problems
37 were excluded. Mediation analyses, through which the associations between the variables were
38 examined, were adjusted for sex and a set of health-related covariates assessed in 2007 and 2011.

39 **Results** Physical activity was associated with decreased levels of sleep problems and depressive
40 symptoms ($P < 0.05$). The association between physical activity and depressive symptoms ($b = -$
41 0.10 , $P < 0.01$) was partly mediated by sleep problems (proportion mediated = 0.36 , $P < 0.01$). The
42 adjustment for depressive symptoms at baseline attenuated the mediation effect (proportion
43 mediated = 0.30 , $P > 0.05$).

44 **Conclusion** Physical activity's favorable contribution to depressive symptoms was mediated partly
45 by sleep, but the mediation effect disappeared after adjusting for the previous depressive symptoms
46 in adulthood.

47

48 **Keywords** Depression, sleep problems, leisure-time physical activity, causality

49

50

51 **INTRODUCTION**

52

53 Depression affects 340 million people globally, and it is one of the leading causes of disability (1).
54 Depression is often a comorbid with other chronic medical conditions, including cardiovascular and
55 psychiatric diseases (1, 2). Early signs of the disorder, such as depressive symptoms, associate also
56 with somatic health outcomes and risks for future mental disorders (2). Although depression has
57 been characterized as one of the psychological disorders that cause the greatest burden of disease
58 worldwide (1, 3), research suggests that it is also one of the most preventable disorders (3).
59 Studying the determinants and mechanisms through which depression develops can provide insights
60 into better prevention of the disorder (3).

61 Along with genetic, psychophysiological and -social determinants, lifestyle factors are
62 contributing to the development and progression of depression (3-5). Physical activity has been
63 regarded as one of the most influential of these factors (5). Recent studies have also shown that
64 approximately 30% of the world's population are physically inactive (6), and the prevalence of
65 physical inactivity is increasing in many countries (6, 7). Studies have demonstrated that even low
66 doses of physical activity may have a protective effect against the onset of depression (7). Literature
67 has also shown that physical activity associates with decreased levels of depression in those with
68 diagnosed depression (7). Some evidence, however, suggests that physical activity may not
69 contribute favorably to depressive symptoms among individuals with a history of depressive
70 episodes (8). To date, the potentially causal association between physical activity and depressive
71 symptoms has not been thoroughly studied, and the importance of identifying mediators affecting
72 the link has been highlighted (1, 4).

73 Sleep has been regarded as one of the most essential psychophysiological and –social
74 factors affecting lifestyles and depression (5, 9). The reciprocal associations between physical
75 activity, sleep problems and depressive symptoms have also been established (5). Based on
76 diagnostic criteria, 6 to 10% of people are suffering from insomnia (9). Studies have also reported

77 that 9%-45% of general population are suffering from some insomnia-related symptoms or sleep
78 problems (9, 10). These problems are increasing in many countries (11, 12). It has also been
79 denoted that highly physically active individuals tend to have a better sleep quality, as well as lower
80 levels of depressive symptoms comparing to physically more inactive ones (13). Previous studies
81 have pointed out the need for targeting the potential causal processes between physical activity,
82 sleep and depressive symptoms (13, 14).

83 Biological factors may partly explain the mechanisms between physical activity, sleep
84 and depressive symptoms. For instance, it has been suggested that sleep problems may result from
85 body temperature's inadequate downregulation, and physical exercising might help in heat
86 acclimation which contributes to better sleep (13). Research has also denoted that physical activity
87 contributes to homeostatic sleep control by increasing the total sleep time and intensity of slow-
88 wave sleep (13, 14). Physically active people are also usually aware of the benefits of sleep for
89 recovery after training sessions (13), and may therefore make efforts to control and structure their
90 sleep patterns. Through these processes, physical activity is likely to contribute to psychological
91 functioning and experienced wellbeing (13, 14). Furthermore, sleep may contribute to alterations in
92 the major neuroendocrine stress system (15). Sufficient sleep may impact the secretion of cortisol
93 (15, 16), which may lead to reduced risk at getting stress-related diseases and disorders including
94 depression (15-17).

95 Longitudinal studies are needed to test the direction of the association between
96 physical activity and depressive symptoms, and the potential mediators affecting the association (1,
97 11, 18). Some previous experimental studies have been criticized for the small sample sizes and
98 differing study protocols, and the advantages of epidemiological studies assessing large samples
99 have been acknowledged (14). Furthermore, modern and sophisticated techniques are also needed to
100 overcome the limitations of earlier methods assessing time dependent processes (19). As the
101 etiology of depression is complex, taking into account the potentially confounding influences of

102 variety of physiological and health related factors has been accentuated (3, 4, 7). Sex, age, body
103 mass index, health behavioral (e.g., smoking), socioeconomic (e.g., education), and social (e.g.,
104 marital status) contributors have been regarded of utmost importance in the development of
105 depression (20-23). These factors may, for instance, affect the stability of adulthood physical
106 activity and sleep patterns that contribute to experienced wellbeing (9, 24).

107 The present study examined the association between physical activity and depressive
108 symptoms using sleep problems as a mediator among adults (aged from 30 to 50) in a prospective,
109 community-based cohort design. Based on the literature, we hypothesized that physical activity
110 contributes to decreased levels of depressive symptoms, and this association is mediated partly by
111 sleep problems. The hypothesis was tested using a mediation model, a standard analyzing tool for
112 assessing such mechanisms, within a sophisticated statistical framework (19). The baseline values
113 of the mediator (sleep problems) and outcome (depressive symptoms), participants' age, sex (2007),
114 body mass index, education, income, employment, marital and smoking statuses (assessed in 2007
115 and 2011) were controlled for to test the strength of the potential association.

116

117 METHODS

118 Study Design and Participants

119 The study participants were from the ongoing longitudinal Cardiovascular Risk in Young Finns
120 study that began in 1980 (25). The original sample consisted of 3596 children and adolescents
121 (83.2% of those invited, 1832 women and 1764 men) from six birth cohorts (aged 3, 6, 9, 12, 15
122 and 18). The sample was collected from five Finnish cities (Helsinki, Kuopio, Oulu, Tampere, and
123 Turku), and the participants were randomly selected from nearby urban and rural areas based on
124 their social security numbers. Informed consent was requested from each subject (or from the
125 parents of small children). The study protocol was approved by the local ethics committees, and
126 conducted according to Helsinki Declaration and American Psychological Association's standards.

127 The sample has been examined in 1980, 1983, 1986, 1989, 1992, 1997, 2001, 2007-
128 2008, and 2011-2012, and medical, psychological and physical-activity data have been collected
129 during these years. In the present study, participants' physical activity was assessed in 2007 and
130 2011, response rate ranging from 53.1% to 60.2% ($n = 1910-2166$) of the original study participants
131 (Supplementary Table 1). Depressive symptoms were measured in 2007 and 2012, and the response
132 rate ranged from 48% to 56.2% ($n = 1725-2020$) of the original participants (Supplementary Table
133 1). Participants' sleep problems were assessed in 2007 and 2011, and the response rate ranged from
134 55.8% to 61.9% ($n = 2006-2226$) of the original examinees (Supplementary Table 1). **The**
135 **participants were aged from 30 to 50 when the present study's data was obtained (in 2007, 2011 and**
136 **2012).**

137 Based on our recent analyses (unpublished results) from the examination in 2011,
138 there were no selective attrition with respect to participants' leisure-time physical activity, which is
139 in line with previous attrition assessments (25, 26). Participants with sleep problems had
140 discontinued the study more often than others ($P < 0.05$). Furthermore, it has also been shown that
141 depressed examinees had discontinued the study more often than other subjects (27). Regarding the
142 potential confounders adjusted for in the present study (unpublished studies), some selective
143 attrition with respect to participants' age, sex, income level, employment, marital and smoking
144 statuses was found. Younger participants, men, the ones with lower income levels and
145 unemployment status had discontinued the study more often than others ($P < 0.05$). Furthermore,
146 smokers and unmarried participants had dropped out of the study more often than others ($P < 0.05$).
147

148 **Measures**

149 Physical Activity

150 Physical activity was measured via self-administered questionnaires. Participants, from whom
151 physical activity was assessed, were aged from 30 to 45 in 2007. The questionnaires consisted of

152 five questions assessing the intensity and frequency of leisure-time physical activity, hours spent on
153 physical activity per week, average duration of a physical activity session, and participation in
154 organized physical activity (8, 26). The answers for each question were coded into 3 ordinal
155 categories (ranging from 1 to 3), higher scores reflecting higher physical activity. A sum score
156 (physical activity index, PAI) of questions was created for each participant, ranging from 5 to 15
157 (Supplementary Table 1). Higher sum scores reflect higher levels of physical activity. The index has
158 been found reliable and valid (8, 26, 28). Physical activity indices have shown to correlate with
159 objective measurements (e.g., ergometer and pedometer tests), coefficients ranging from small to
160 moderate (26, 29). The findings are in the same direction with previous literature demonstrating that
161 self-reports correlate with objective physical activity measures (30, 31).

162 Sleep problems

163 Participants' sleep quality was measured with four items reflecting participants' experiences of
164 sleep problems (32) in 2011 when they were aged from 34 to 49. The questions assessed troubles
165 falling asleep, staying asleep (i.e., waking up too early and problems in getting back to sleep),
166 waking up several times per night, and waking up after usual amount of sleep and feeling tired and
167 worn out. The response options ranged from one to six (1 = not at all, 6 = every night). An average
168 of the items was calculated for each participant, higher scores reflecting higher level of sleep
169 problems. The Cronbach's α for the items was 0.77 in 2007, and 0.76 in 2011, indicating good
170 internal consistency for the items. The measure has shown to be appropriate among patient samples
171 as well as in observational, population-based settings (27, 32). There exists evidence indicating that
172 subjective evaluations of sleep correlate with objective measurements (33).

173 Depressive symptoms

174 Participants' depressive symptoms were assessed in 2012 when they were aged from 35 to 50. Beck
175 Depression Inventory II (BDI-II) (34), consisting of 21 symptoms with a range from 0 (no
176 symptoms) to 3 (severe level of depressive symptoms), was used. A sum score of all items was

177 computed for each study subject (Supplementary Table 1), and no missing items were allowed (34).
178 Items reflecting participants' sleeping habits ("I'm sleeping as well as before"), and feelings of
179 fatigue ("I am not more tired than usually") were excluded from the sum score due to the overlap
180 with the items assessing sleep problems (32). The reliability estimate (Cronbach's α) for the
181 depressive symptom scores was 0.93 both in 2007 and 2012, indicating an excellent internal
182 consistency for the items. BDI-II evaluates variation in symptom severity among normal population
183 as well as in clinical samples (34, 35). The instrument has shown to correlate with other widely
184 used scales for depression within non-clinical and clinical contexts, and it has shown to be
185 applicable screening tool for future depressive disorder (36).

186

187 Covariates

188 Participants' baseline sleep problems and symptoms of depression (32, 34) assessed in 2007 were
189 controlled for in the mediation analyses (Tables 1-2). General confounders (sex, age and body mass
190 index), socioeconomic factors, and marital as well as smoking statuses were also adjusted for in the
191 models (20-23) (Tables 1-2). The variables (excluding sex and age) were adjusted for in the
192 baseline in 2007, as well as in 2011 to control for the potential time-related change within them.
193 Participants' socioeconomic status was determined via three indices both in 2007 and 2011;
194 educational level was assessed via a 3-category scale (1 = comprehensive school, 2 = secondary
195 education, not academic 3 = academic education). Participants' income level was assessed with an
196 8-point scale (1 = <10 000 euros, 8 = >70 000 euros/ year) in 2007, and with a 13-point scale in
197 2011 (1 = <5 000 euros, 13=> 60 000 euros/ year). Employment status was examined with a
198 question "Are you unemployed in the present moment?" (1 = no, 2 = yes) during the years 2007 and
199 2011. **Participants' marital statuses were examined using a 5-category scale in 2007 (1 = widowed,**
200 **2 = unmarried, 3 = divorced/ living separately, 4 = in a civil partnership, 5 = married) and using a 6-**
201 **category instrument in 2011 (1= widowed, 2 = unmarried, 3 = divorced/ living separately, 4 =**

202 cohabiting, 5 = in a civil partnership, 6= married). Smoking status was examined via a 5-category
203 scale (1 = smokes a cigarette per day or more, 2 = smokes once in a week, 3 = smokes less than
204 once in a week, 4 = has quitted smoking, 5 = has never smoked) during the year 2007, and with a 6-
205 category scale (1= smokes a cigarette per day or more, 2= smokes once in a week or more, not
206 daily, 3= smokes less than once in a week, 4= has temporarily quitted smoking, 5= has quitted
207 smoking, 6= has never smoked) in 2011.

208 **Statistical Analyses**

209

210 The associations between physical activity (2007), sleep problems (2011) and depressive symptoms
211 (2012) were first examined with correlational analyses. Thereafter, the mediation analyses were
212 conducted within a modern framework of statistical testing (19, 37, 38). We studied first the model
213 in which physical activity was expected to contribute to decreased levels of depressive symptoms,
214 and whether the association was mediated by sleep problems (Figure 1). The results were further
215 examined with adjusting for the mediator's and outcome's values at baseline, participants' sex, age,
216 body mass index, socioeconomic factors, marital and smoking statuses. We also tested which
217 covariate(s) potentially affected the mediation by controlling for each of them separately in the
218 model. Furthermore, we conducted the same analyses using the standardized cut off values for BDI-
219 II (0-13 = no symptoms of depression/ minimal depression, ≥ 14 = mild, moderate or severe
220 depression) (34, 35).

221 The mediation analysis used in this study is applicable in estimating both linear and
222 nonlinear relationships, parametric and nonparametric models, as well as variables with different
223 measurement scales (19, 37). The method relies on the assumption of sequential ignorability,
224 according to which the independent variable should be ignorable of the observed pretreatment
225 covariates, and the mediator should be independent of the observed treatment and pretreatment
226 confounders (19, 37, 38). Conducting mediation analysis requires two models, one for the mediator

227 and one for the outcome. Missing values were removed from the present data before the estimation
228 of the mediation models, as both models must have identical number of observations in the same
229 order within the data. **The potential confounding factors, which could not be regarded as perfectly**
230 **valid ordinal or interval variables (sex, education, employment, marital and smoking statuses), were**
231 **defined as factors (nominal variables) with the use of a reference category in the mediation models.**

232 After fitting the models, the results were generated using the algorithm designed for
233 parametric, semiparametric and nonparametric models (Algorithm 2) (38). This algorithm was also
234 applied due to the potential skewness of the variables' distributions (38, 39). The algorithm is based
235 on nonparametric bootstrap (38), which relies on random sampling with replacement method. Along
236 with producing mediation, direct and total effects, the algorithm generates uncertainty estimates
237 including confidence intervals and p-values. Confidence intervals were calculated using percentile
238 method, and p-values were calculated from percentile-based confidence intervals. All the bootstrap
239 calculations were performed with 1000 resamples (simulations).

240 Sensitivity analysis for mediation test is based on the correlation between the error for
241 the mediation model, and the error for the outcome model (19, 37, 38). The sensitivity parameter
242 rho (ρ) represents the model's deviance from the sequential ignorability assumption. Under
243 sequential ignorability, ρ is zero, and nonzero values ranging from -1 to 1 indicate departures from
244 the ignorability assumption (37, 38). The goal of sensitivity analysis is to quantify the degree to
245 which the key identification assumption is violated (37). It has been suggested that the degree of
246 sensitivity can be evaluated in comparison to other studies (38, 40), and in conjunction with expert
247 opinion (38). Given the importance of sequential ignorability, it has been argued that a mediation
248 analysis is not complete without a sensitivity assessment (38). P-values < 0.05 were considered
249 significant. The analyses were performed via SPSS (version 24.0) and R-software (version 3.1,
250 mediation package 4.4.6).

251 **RESULTS**

252 Descriptive statistics of the sample are presented in Tables 1 and 2, as well as in Supplementary
253 Tables 1 and 2. Due to the non-normal distributions regarding depressive symptoms and sleep
254 problems, square root transformations were conducted. Thereafter, the variables were standardized
255 to improve the comparability of the results. Physical activity correlated negatively with sleep
256 problems and symptoms of depression in most tests ($P < 0.05$). Positive correlations between sleep
257 problems and depressive symptoms were found ($P < 0.05$) (Table 3).

258 The favorable contribution of physical activity to depressive symptoms ($b = -0.10$, $P <$
259 0.01) was partly mediated by sleep problems (proportion of total effect via mediation = 0.36, $P <$
260 0.01 , $\rho = 0.36$) (Table 4, Unadjusted analyses). After adjusting for the mediator's and outcome's
261 baseline values (2007), participants' sex, age (2007), body mass index, socioeconomic factors,
262 marital and smoking statuses (2007 and 2011), the results turned into non-significance (proportion
263 mediated = 24.06, $P > 0.05$) (Table 4, Adjusted analyses). After testing for which of the covariates
264 affected the mediation effect, the baseline value of depressive symptoms (2007) attenuated it
265 (proportion mediated = 0.30, $P > 0.05$). Approximately similar results were found when the
266 outcome, depressive symptoms assessed in 2012, was used as a dichotomized variable. Within these
267 analyses, the contribution of physical activity to depressive symptoms ($b = -0.02$, $P < 0.01$) was
268 partly mediated by sleep problems (proportion mediated = 0.16, $P < 0.01$). The results became
269 nonsignificant when the covariates were controlled for (proportion mediated = 0.08, $P > 0.05$).
270 After testing for which of the covariates affected the mediation effect, the baseline value of
271 depressive symptoms (2007) attenuated it (proportion mediated = 0.09, $P > 0.05$).
272

273 DISCUSSION

274
275 This study examined the associations between physical activity, sleep problems and depressive
276 symptoms, and whether the potential contribution of physical activity to depressive symptoms were

277 mediated by sleep problems. The results were further tested by adjusting the models for mediator's
278 and outcome's values at baseline (2007), participants' sex, age (2007), body mass index,
279 socioeconomic factors, marital and smoking statuses (2007 and 2011). Moreover, the mediation
280 analyses' robustness was examined with sensitivity analyses.

281 The results indicated that physical activity was associated with decreased levels of
282 sleep problems and depressive symptoms, which is in line with previous studies (4, 7). The
283 favorable contribution of physical activity to symptoms of depression was partly mediated by sleep
284 problems, which is in agreement with our hypothesis. When the covariates were controlled for, the
285 significant mediation effect disappeared. Adjusting for depressive symptoms at baseline attenuated
286 the mediation effect, whereas other potential confounders did not contribute to the tested
287 association. As the results were approximately similar when the depressive symptoms were studied
288 as a dichotomized outcome, we gained supportive evidence for the suggestion that the lost impact of
289 sleep as a mediator was due to the pre-existing symptoms of depression. Furthermore, the
290 sensitivity analyses indicated that unobserved confounding exists in the study.

291 It has been suggested that physical activity's favorable effects on depressive
292 symptoms might be mediated through sleep due to physiological processes. For instance, physical
293 activities might associate with body temperature's downregulation, which contributes to improved
294 sleep (13). Physical activities may also boost body's catabolic activity, which facilitates body
295 restoration during rest (14, 41). Improved sleep is likely to associate with psychological functioning
296 and wellbeing (13, 14). Sufficiency of sleep may also contribute to hormonal balance impacting
297 cortisol secretion associating with mood and psychological wellbeing (15-17).

298 The existing literature has not been, however, able to fully explain the sleep-
299 promoting efficacy of physical activities (14). As adjusting for the baseline of depressive symptoms
300 attenuated the sleep problems' mediating effect in the relation between physical activity and
301 depressive symptoms, it seems possible that physical activity's favorable effect on mood mediated

302 by sleep disappears in people who have pre-existing symptoms of depression. Previous research has
303 also shown that physical activity is not associated with progression of depression in adulthood (8).
304 Depressed people often experience feelings of sadness, failure, guilt, disappointment and irritation
305 (33). They also tend to suffer from a lack of healthy appetite, self-belief, motivation and ability to
306 start and maintain distinct activities (33). Thus, it is possible that depressed people's
307 psychophysiological and behavioral predispositions mismatch with those that are needed in getting
308 interested and engaging in physical activities. It is also possible that pre-existing depressive
309 symptoms associate with difficulties with sleep regulation (4). Such difficulties may hamper body
310 restoration during rest, and hinder physical activity's favorable effects on mood mediated by sleep.
311 Thus, it is possible that the pre-existing symptoms of depression predispose an individual to such
312 psychophysiological conditions and behaviors that may not contribute to physically active lifestyle
313 and related benefits as good sleep through which the favorable effects of physical activity on
314 psychological wellbeing could partly come.

315

316 Limitations

317

318 Proportion of total effects via mediation was quite large (36%) in the unadjusted model in which
319 BDI-II was used as continuous variable, although the results were not perfectly robust ($\rho=0.36$). We
320 cannot perfectly determine whether the potential mediator-outcome confounding, exposure-
321 mediator interaction, or mediator-outcome confounding affected by the exposure introduced bias
322 into our data (42), but the sensitivity analyses gave us the possibility to evaluate the degree to which
323 the unobserved confounding might have affected the results. Unobserved confounding's existence
324 is, however, unavoidable especially in observational studies where the study designs are not
325 randomized (37, 38). Furthermore, we were able to adjust for the baseline values of the mediator
326 and outcome variables along with other covariates with this observational design, but even after

327 controlling for the potential time-related change within these variables our possibility to consider
328 causality is limited. Furthermore, participants did not provide information regarding each variable
329 across the measurement years, which diminished the sample size to some degree. **Sample attrition**
330 **can be regarded as a major limitation of the study as it can contribute to both under- and**
331 **overestimation of the associations. The study was also non-experimental. Due these reasons, the**
332 **results should be interpreted with caution.** Finally, the assessments concerning the participants'
333 physical activity, sleep problems and symptoms of depression were self-reported, and therefore the
334 possibility of subjective bias cannot be perfectly excluded. Self-reports have, however, shown to be
335 correlated with objective measurements and diagnoses (29-31, 33-35).

336

337

338 Strengths

339

340 The study's strengths were its prospective and population-based design. Validated and clinically
341 relevant measures (26, 32, 34) were used, and a set of relevant covariates were controlled for.
342 Furthermore, the mediation analyses were conducted within a modern and sophisticated framework
343 of causal inference (37, 38).

344

345 Conclusions

346

347 This population-based, prospective study showed that the association between physical activity and
348 decreased levels of depressive symptoms was mediated partly by sleep problems in adults.
349 However, controlling for the pre-existing depressive symptoms attenuated this finding. Thus,
350 physical activity's favorable contribution to depressive symptoms was mediated partly by sleep, but
351 the mediation effect disappeared after adjusting for the previous depressive symptoms in adulthood.

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491

492 **CONFLICTS OF INTEREST**

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494 The authors have no conflicts of interest to declare. The results of the study are presented clearly,
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497

498 **Figure 1.** Sleep problems mediating the association between physical activity and depressive
499 symptoms

Table 1. Descriptive statistics for the complete sample ($n = 1018$).

Variables	Mean/SD/ n (%)	Range
Confounding factors ¹		
Sex (1980)		0-1
Females	601 (59.0)	
Males	417 (40.9)	
Age, years (2007)	38.1±5.0	30-45
Body mass index (2007)	25.8±4.7	16.6-58.8
Body mass index (2011)	26.3±4.9	17.0-58.5
Education (2007) ²	2.2±0.5	1-3
Education (2011)	2.3±0.5	1-3
Income (2007)	3.5±1.5	1-8
Income (2011)	7.3±3.0	1-13
Employment status (2007)		0-1
Employed	987 (97.0)	
Not employed	31 (3.0)	
Employment status (2011)		0-1
Employed	973 (95.6)	
Not employed	45 (4.4)	
Marital status (2007) ³	4.2±1.1	1-5
Marital status (2011) ⁴	4.9±1.5	1-6
Smoking status (2007) ⁵	4.0±1.4	1-5
Smoking status (2011) ⁶	4.9±1.7	1-6
Sleep problems (2007)	1.5±0.3	1-2.5
Depressive symptoms (2007)	1.6±1.4	0-6.2
Independent/ mediator/ dependent variables		
Physical activity index (2007)	8.9±1.8	5-15
Sleep problems (2011)	1.5±0.3	1-2.5
Depressive symptoms (2012)	1.4±1.3	0-7.2
Depressive symptoms (dichotomized scores) (2012)		0-1
No depression/ minimal depression	955 (93.8)	
Mild, moderate or	63 (6.2)	

severe depression

¹The dichotomized variables are dummy coded (0-1).

²1= comprehensive school, 3= academic education both in 2007 and 2011

³1= widowed, 5= married

⁴1= widowed, 6= married

⁵1= smokes a cigarette per day or more, 5=has never smoked

⁶1= smokes a cigarette per day or more, 6= has never smoked

Table 2. Descriptive Z-statistics for the complete sample ($n = 1018$).¹

Variables	Range
Confounding factors	
Sex (1980)	-0.98-1.02
Age, years (2007)	-1.49-1.51
Body mass index (2007)	0.83-1.99
Body mass index (2011)	0.82-1.88
Education (2007)	-2.36-1.58
Education (2011)	-2.44-1.58
Income (2007)	-1.60-2.89
Income (2011)	-2.06-1.81
Employment status (2007)	-0.21 4.82
Employment status (2011)	-0.24 4.18
Marital status (2007)	-2.85 0.74
Marital status (2011)	-2.53 0.75
Smoking status (2007)	-1.84-0.78
Smoking status (2011)	-2.03-0.71
Sleep problems (2007)	-1.42-2.89
Depressive symptoms (2007)	-1.19-2.89
Independent/mediator/dependent variables	
Physical activity index (2007)	-2.10-3.41
Sleep problems (2011)	-1.47-3.04
Depressive symptoms (2012)	-1.10-4.15

¹Excluding the dichotomized scores for depressive symptoms (presented in Table 1), the scores are standardized with a mean of 0 and standard deviation of 1

Table 3. Correlation coefficients between physical activity, sleep problems and symptoms of depression ($n = 1365$ - 2161).

	1.	2.	3.	4.
1. Physical activity (2007)				
2. Sleep problems (2007)		-0.04		
3. Sleep problems (2011)	-0.08**		0.54**	
4. Depressive symptoms (2007)	-0.09**	0.41**		0.37**
5. Depressive symptoms (2012)	-0.09**	0.30**	0.35**	
				0.62**

$P < 0.05^*$

$P < 0.01^{**}$

Table 4. Sleep problems mediating the association between physical activity and depressive symptoms (unadjusted analyses, $n = 1270$; adjusted analyses, $n = 1018$).

	Unadjusted analyses			Adjusted analyses ¹				
	b/ Prop. Med.	95%CI ²	P- value	ρ (ACME) ³	b/ Prob. Med.	95%CI	P- value	ρ (ACME)
ACME ⁴	-0.03	-0.06 to -0.02	<0.01	0.36	-0.00	-0.01 to 0.00	0.29	0.19
ADE ⁵	-0.06	-0.11 to -0.01	0.02		0.00	-0.05 to 0.05	0.90	
Total Effect	-0.10	-0.15 to -0.04	<0.01		-0.00	-0.05 to 0.05	0.99	
Proportion Mediated	0.36	0.18 to 0.76	<0.01		24.06	-3.77 to 2.46	0.93	

¹The analyses were adjusted for mediator and outcome variables' baseline values, participants' sex, age, body mass index, socioeconomic factors, marital and smoking statuses

²Nonparametric bootstrap confidence intervals with the percentile method were examined

³Rho, sensitivity parameter

⁴ACME, average causal mediation effect

⁵ADE, average direct effect

Supplementary Table 1. Descriptive statistics for the original sample's continuous variables ($n = 1725\text{-}3596$).

Variables	All ¹ <i>n</i>	Mean/ SD	Range
Confounding factors			
Age, years (2007)	3596	37.4±5.0	30-45
Body mass index 2007	2170	26.0±4.8	16.6-58.8
Body mass index 2011	2049	26.5±5.1	16.2-58.5
Income (2007)	2146	3.5±1.6	1-8
Income (2011)	1941	7.4±3.1	1-13
Sleep problems (2007)	2226	2.3±1.1	1-6
Depressive symptoms (2007)	2020	4.5±5.9	0-40
Independent/mediator/dependent variables			
Physical activity index (2007)	2166	8.8±1.8	5-15
Sleep problems (2011)	2006	2.3±1.0	1-6
Depressive symptoms (2012)	1725	4.2±5.9	0-52

Supplementary Table 2. Descriptive statistics for the original sample's categorical variables ($n=1725$ - 3596).

Variables	All <i>n</i>	Variables' categories	Variables' categories' <i>n</i> (%)	Range
Confounding factors				
Sex (1980)	3596	Females Males	1832 (50.9) 1764 (49.1)	1-2
Education (2007)	2228	Comprehensive school Secondary education Academic	110 (4.9) 1569 (70.4) 549 (24.6)	1-3
Education (2011)				
Education (2011)	2002	Comprehensive school Secondary education Academic	78 (3.9) 1415 (70.7) 509 (25.4)	1-3
Employment status (2007)	2182	Employed Not employed	2092 (95.9) 90 (4.1)	1-2
Employment status (2011)	1957	Employed Not employed	1851 (94.6) 106 (5.4)	1-2
Marital status (2007)	2223	Widowed Unmarried Divorced/ living separately In a civil partnership Married	6 (0.3) 347 (15.6) 138 (6.2) 497 (22.4) 1235 (55.6)	1-5
Marital status (2011)	2000	Widowed Unmarried Divorced/ living separately Cohabiting In a civil partnership Married	8 (0.4) 269 (13.5) 151 (7.6) 346 (17.3) 38 (1.9) 1188 (59.4)	1-6
Smoking status (2007)	2224	Smokes a cigarette per day or more	411 (18.5)	1-5

		Smokes once in a week	91 (4.1)	
		Smokes less than once in a week	110 (4.9)	
		Has quitted smoking	511 (23.0)	
		Has never smoked	1101 (49.5)	
Smoking status (2011)	1999	Smokes a cigarette per day or more	306 (15.3)	1-6
		Smokes once in a week or more, not daily	58 (2.9)	
		Smokes less than once in a week	87 (4.4)	
		Has temporarily quitted smoking	28 (1.4)	
		Has quitted smoking	502 (25.1)	
		Has never smoked	1018 (50.9)	
Dependent variable				
Depressive symptoms (dichotomized scores) (2012)	1725	No symptoms of depression/ minimal depression	1592 (92.3)	0-1
		Mild, moderate or severe depression	133 (8.8)	