

## 1        **Comparison of the Physical Activity Frequency Questionnaire (PAFQ) with** 2        **accelerometry in middle-aged and elderly: the CoLaus study**

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34

35 **ABSTRACT**

36 **Objective:** The Physical Activity Frequency Questionnaire (PAFQ) has been used in several studies, but  
37 its validation dates from 1998. We aimed to compare the PAFQ with accelerometry data for measuring  
38 activity.

39 **Design:** Cross-sectional analysis conducted among individuals aged 35-75 years within the prospective  
40 CoLaus study in Switzerland. All participants were requested to complete the PAFQ and wear a wrist-  
41 worn accelerometer for 14 consecutive days. Spearman correlation, Lin's concordance coefficient and  
42 Bland-Altman plots were performed to compare PAFQ and accelerometry data.

43 **Results:** 1752 participants (50.7% female, age range 45.2-87.1 years) had complete information on the  
44 PAFQ and accelerometer. Compared to the accelerometer, the PAFQ overestimated total, light,  
45 moderate and vigorous activity by a median [interquartile range] of 143 [34.5; 249], 72 [12; 141], 23 [-  
46 46; 100] and 13 [-1; 41] minutes/day, respectively, and underestimated sedentary behaviour by 123  
47 [14; 238] minutes/day. Spearman's correlation coefficients ranged from 0.171 for vigorous PA and  
48 0.387 for total PA and sedentary behaviour, and Lin's concordance coefficients ranged from 0.044 for  
49 vigorous PA and 0.254 for moderate-to-vigorous PA, indicating a poor correlation and concordance.  
50 The difference between PAFQ and accelerometer increased with increasing time spent in each activity  
51 level.

52 **Conclusion:** There is limited agreement between the measures of activity obtained by PAFQ compared  
53 to accelerometers, suggesting that these tools measure activity through different angles. Although  
54 there is some degree of comparability, they should be considered as complementary tools to obtain  
55 comprehensive information of individual and population activity levels.

56

57 **Keywords:** physical activity; sedentary behaviour; questionnaire; accelerometry; comparison;  
58 Switzerland.

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**61 INTRODUCTION**

62 Physical activity (PA) is an important modifiable risk factor in the prevention of non-  
63 communicable diseases, including cardiovascular disease, diabetes mellitus, several types of cancer  
64 and depression [1, 2]. Several methods exist for assessing PA and sedentary behaviour (SB) [3]. Self-  
65 reported measures (e.g. questionnaires) have been widely used in epidemiological studies because of  
66 their low cost and low burden to participants [4]. Recently, accelerometers have become more  
67 accessible and have allowed measuring the intensity and duration of PA objectively in large samples  
68 [5-7]. However, discrepancies emerged when comparing PA data collected by questionnaire and by  
69 accelerometry in large populations [8, 9]. Correlations are low, and self-reported measures either over-  
70 or underestimate PA relative to accelerometry. Also, SB has been recently suggested to impact  
71 cardiovascular disease independent of PA [10-13]. Still, few PA questionnaires have been validated or  
72 compared with accelerometers for the assessment of SB [14-16].

73 The physical activity frequency questionnaire (PAFQ) was developed in 1998 to measure total  
74 and activity-specific energy expenditure in the population of Geneva, Switzerland [17]. The PAFQ  
75 focuses mainly on light and moderate PA and has been used in several studies to quantify physical  
76 activity [18-23], including studies as CoLaus [24] and Bus Santé [25]. Validation of the PAFQ was  
77 performed in 41 volunteers using a heart rate monitor in 1998 [17], which was captured in a large  
78 systematic review comparing direct and self-reported measures of activity [9]. The validation study  
79 reported a good correlation ( $r = 0.76$ ) between total energy estimated by the PAFQ and by a heart rate  
80 monitor, and did not find statistically significant differences between estimates from the PAFQ and the  
81 heart rate monitor [17]. Since then, no further validations have been performed and it has not been  
82 compared with alternative methods such as accelerometry. In the CoLaus study, accelerometers were  
83 recently added as an additional tool to measure PA. How the PAFQ compares to PA measured with  
84 accelerometers, and whether these two methods are interchangeable or not remains unclear.

85           The assessment of physical activity can be influenced by an individuals' characteristics, as well  
86 as their geographical and cultural context. The reliability and validity of self-reported measures is  
87 limited by recall bias or social desirability [26]. In particular, light intensity physical activities (LPA) such  
88 as household chores, are harder to recall than activities of higher intensity [26]. Recall bias and  
89 reporting errors may also occur more often in older populations, in whom cognitive impairment is  
90 more likely [27]. Social desirability is another factor that might influence physical activity  
91 measurement, especially for women and individuals with a higher body mass index (BMI) [28]. In  
92 addition, individuals in retiring age (i.e. 65 years in Switzerland) have a different activity behaviour  
93 than working individuals.

94           Therefore, in a large population of middle-aged and older adults, we aimed to compare activity  
95 measured with the PAFQ to activity measured by accelerometry, and to investigate whether these  
96 comparisons differed by categories of gender, age and BMI.

## 97 **METHODS**

### 98 *Participants*

99           The detailed process of the recruitment of the CoLaus study and the follow-up procedures  
100 have been described previously [24]. Briefly, the CoLaus study is a population-based cohort study  
101 exploring the biological, genetic, and environmental determinants of cardiovascular disease. A non-  
102 stratified, representative sample of the population of Lausanne (Switzerland) was recruited between  
103 2003 and 2006 based on the following inclusion criteria: i) age 35–75 years and ii) willingness to  
104 participate. The second follow-up occurred 10.9 years after the baseline survey and included an  
105 optional module assessing the participant's PA for 14 days with an accelerometer. For this study, we  
106 performed a cross-sectional analysis using data of the second follow-up only.

107 *Exclusion criteria*

108 Participants were excluded if they i) did not fill in the PAFQ, ii) did not wear the accelerometry,  
109 or iii) had an insufficient number of valid days for accelerometry (less than 5 weekdays or 2 weekend  
110 days).

111 *Measurements*

112 *Physical activity frequency questionnaire*

113 The PAFQ is a self-administered measure of the total and activity specific energy expenditure.  
114 Detailed information on the PAFQ can be found elsewhere [17, 29]. Briefly, the questionnaire lists 70  
115 types of PA from various domains (e.g. occupational, housework, leisure time, sports, etc.). The  
116 participants indicated the number of days in the past week (0 to 7) and the duration per day (0 to 10h,  
117 15 min increment) for each activity.

118 For the purpose of this study, each type of activity was categorized into SB (<2 metabolic  
119 equivalent of tasks – METs), LPA (2 to <3 METs), MPA (3-6 METs) and VPA (>6 METs) according to the  
120 compendium of physical activities[30, 31] (see **Additional file 1**). Total PA was defined as the sum of  
121 LPA, MPA and VPA. For each item of the PAFQ, the time spent per week was computed as average  
122 hours per day×number of days performing the activity. For each category of item (i.e. corresponding  
123 to SB, LPA, MPA or VPA), the times were summed up and divided by 7 to estimate an average daily  
124 time. For example, if the participant spent 2 hours/day housekeeping (MPA) and performed this  
125 activity for 3 days per week, then the total time was 2×3=6 hours/week; if the participant also spent 1  
126 hour/day sewing and ironing (MPA) and performed this activity every day, then the total time was  
127 1×7=7 hours/week, and the average daily time spent in MPA activities would be (6+7)/7=1.85 hours or  
128 111 minutes.

129 Usual sleep time (in minutes) was assessed by asking the participants when they went to bed  
130 and when they woke up, and the number of minutes on non-sleep time (NST) was computed as

131  $NST=1440$ –sleep time. As participants tended to under or overestimate time spent in the different  
132 activities, a standardization was performed as follows: First, we calculated  $T$ , the total amount of time  
133 spent in SB, LPA; MPA and VPA activities. Second, we computed the percentage of time dedicated to  
134 each type of activity, i.e.  $P_{SB}=\text{time spent in SB}/T$ . Third, we computed the standardized time spent on  
135 each type of activity by multiplying the non-sleep time by the percentage of time spent in each activity  
136  $ST_{SB}=T \times P_{SB}$ . A detailed example of calculation is provided in **Additional file 2**.

### 137 *Accelerometer Physical Activity*

138 Accelerometry-based PA was assessed using a wrist-worn triaxial accelerometer (*GENEActive*,  
139 Activinsights Ltd, UK). This device has been validated against reference methods [32]. The intra- and  
140 inter-instrument coefficients of variation were 1.4% and 2.1%; and high correlations with reference  
141 methods such as mechanical shaking ( $r=0.98$ ) and indirect calorimetry ( $r=0.83$ ) have been reported  
142 [32]. The accelerometers were pre-programmed with a 50 Hz sampling frequency and subsequently  
143 attached to the participants' right wrist. Participants were requested to wear the device continuously  
144 for 14 days in their free-living conditions. Accelerometry data were downloaded using the *GENEActiv*  
145 software version 2.9 (*GENEActiv*, Activinsights Ltd., United Kingdom) and collapsed into 60 s epoch  
146 files.

147 Data were analysed using the *GENEActiv* macro file "General physical activity" version 1.9  
148 based on intensity cutoffs validated among middle-aged adults: SB (<241 g.min), light (241–338 g.min),  
149 moderate (339-1131 g.min) and vigorous ( $\geq 1132$  g.min) PA.[32] Total PA was defined as the sum of  
150 light, moderate and vigorous PA. Conversely, no information was available regarding the criteria used  
151 for non-wear time (proprietary). Based upon a previous study [33], a valid day was defined as  $\geq 10$   
152 hours (i.e. 600 min) and  $\geq 8$  hour (i.e. 480 min) of diurnal wear-time on weekdays and weekend days,  
153 respectively. For each participant, the proportion of time (in percentage) spent in SB, LPA, MPA and  
154 VPA was averaged for all valid days.

155 *Other covariates*

156           Gender was self-reported. Age at the time of the examination was rounded to the nearest year  
157 and further categorized into two groups: <65 and ≥65 years, to reflect the working and retired  
158 individuals. Body weight and height were measured with participants barefoot and in light indoor  
159 clothes. Body weight was measured in kilograms to the nearest 100 g using a Seca® scale (Hamburg,  
160 Germany). Height was measured to the nearest 5 mm using a Seca® (Hamburg, Germany) height gauge.  
161 Body mass index (BMI) was calculated by  $\text{weight}(\text{kg})/\text{height}(\text{m})^2$ , and categorized into low (<25 kg/m<sup>2</sup>)  
162 and high (≥25 kg/m<sup>2</sup>) BMI.

163 *Statistical analysis*

164           Statistical analyses were performed using Stata version 15.1 for Windows (Stata Corp, College  
165 Station, Texas, USA). Descriptive results were expressed as number of participants (percentage) for  
166 categorical data, and average ± standard deviation (SD), or median [interquartile range (IQR)] for  
167 continuous data. Lin's concordance correlation coefficients and corresponding 95% confidence  
168 intervals (CI) were used to measure the agreement between PAFQ and accelerometer data [34].  
169 Interpretation of Lin's concordance coefficients was as follows: <0.90 poor; 0.90 to 0.95 moderate;  
170 0.95 to 0.99 substantial; >0.99 almost perfect [35]. Spearman correlations were used to associate PAFQ  
171 and accelerometer data; 95% CIs were obtained by bootstrapping with replacement, using 1000  
172 iterations and bias-corrected values. Bland–Altman plots were used to visualize the extent of  
173 (dis)agreement between the two measures. Interpretation of Spearman correlation was as follows: 0.0  
174 to 0.3 negligible; 0.3 to 0.5 low; 0.5 to 0.7 moderate; 0.7 to 0.9 high; 0.9 to 1.0 very high correlation  
175 [36].

176           As a sensitivity analysis, we excluded participants with extreme sleep durations (<4 or >10  
177 hours/day).

178           Simple linear regressions were performed to assess whether differences between the PAFQ  
179 and accelerometer regarding SB or PA were associated with gender (men vs. women), age (<65 vs. ≥65

180 years) and BMI (low vs. high) groups, for each group separately. Groups were coded as dichotomous  
181 (0/1) variables, whereby the categories of women, age <65 years and low BMI were considered as  
182 reference.

$$183 \quad \Delta = \alpha + \beta \cdot \text{group}$$

184 Where  $\Delta$  is the difference between the PAFQ and the accelerometer regarding time spent in  
185 SB and the different levels of PA. A statistically significant value of  $\alpha < 0$  indicates overestimation by the  
186 accelerometer, and underestimation otherwise. A statistically significant value of  $\beta$  indicates that  $\Delta$   
187 differs between groups. In addition, multivariable linear regressions were performed including gender,  
188 age and BMI groups as independent variables, allowing adjustment for each other. Statistical  
189 significance was considered for a two-sided test with  $p < 0.05$ .

## 190 RESULTS

### 191 *Characteristics of participants*

192 Of the initial 4881 participants, 1752 (35.9%) were eligible for the analysis. The selection  
193 procedure is shown in **Figure 1** and the characteristics of included and excluded participants are  
194 presented in **Supplementary table 1**. Included participants were younger, less likely to be female and  
195 had a lower BMI. The mean age (SD) of the included participants was 60.5 (9.4) and 50.7% of them  
196 were female.

### 197 *Activity levels, correlations and concordance*

198 Time spent in SB and different levels of PA (in minutes per day or as percentage of time)  
199 according to the PAFQ and accelerometer are presented in **Table 1** as median [interquartile range].  
200 Compared to the accelerometer, the PAFQ overestimated total PA, LPA, MPA and VPA by 143 [34.5;  
201 249], 72 [12; 141], 23 [-46; 100] and 13 [-1; 41] minutes, respectively, and underestimated SB by 123  
202 [14; 138] minutes. When the results were expressed as percentage of time, the PAFQ overestimated



203 LPA, MPA and VPA by 7.5% [1.1; 14.6], 1.7% [-5.3; 10.1] and 1.3% [-0.1; 4.2], respectively, and  
204 underestimated SB by 14.7% [4.1; 25.7].

205 Spearman correlation and Lin's concordance coefficients of SB and different levels of PA  
206 between the PAFQ and the accelerometer are presented in **Table 2**. When the results were expressed  
207 in minutes, Spearman coefficients (95% CI) ranged between 0.171 (0.124; 0.221) for VPA and 0.370  
208 (0.325; 0.409) for SB, indicating a neglectible to low correlation, whereas total PA had a correlation of  
209 0.373 (0.331; 0.417), indicating a low correlation. Lin's concordance coefficients ranged between 0.044  
210 (0.035; 0.053) for VPA and 0.250 (0.218; 0.282) for MVPA, indicating a poor concordance. When the  
211 results were expressed as percentage of time, Spearman coefficients ranged between 0.171 (0.126;  
212 0.217) for VPA and 0.387 (0.346; 0.426) for SB, indicating a neglectible to low correlation. Lin's  
213 coefficients ranged between 0.045 (0.036; 0.055) for VPA and 0.254 (0.221; 0.286) for MVPA, indicating  
214 a poor concordance. All observed Spearman correlations and Lin concordance coefficients were  
215 statistically significant at  $p < 0.001$ .

216 The Bland-Altman plots illustrating the absolute differences in time estimated with the PAFQ  
217 and the accelerometer are presented in **Figure 2**. Both for absolute time and proportion of time, there  
218 were positive mean differences for LPA, MPA, VPA and MVPA, indicating that the PAFQ overestimates  
219 these behaviours compared to the accelerometer, and a negative mean difference for SB indicating  
220 that SB is underestimated in the PAFQ compared to accelerometry. The limits of agreement were  
221 wide for all activity levels, meaning that there are large differences in estimated time spent in all  
222 activity levels comparing accelerometer and PAFQ. An increased discrepancy between accelerometer  
223 and PAFQ was seen at more minutes of time spent in LPA, MPA; VPA and MVPA, while no clear trend  
224 was visible for SB.

#### 225 *Sensitivity analysis*

226 Results after excluding 40 participants with extreme sleeping times (<4 or >10 hours/day) are  
227 presented in **Supplementary tables 2 and 3**. Overall, no changes in the differences between PAFQ and

228 accelerometry (**Supplementary table 2**) and in the Spearman correlation and Lin's concordance  
229 coefficients (**Supplementary table 3**) were observed.

### 230 *Differences between gender, age and BMI groups*

231 Results according to gender, age and BMI groups are presented in **Table 3**. Compared to  
232 accelerometry data, both men and women underestimated SB and MPA, and overestimated LPA, VPA  
233 and total PA when using the PAFQ. Women overestimated LPA and underestimated MPA to a larger  
234 extent than men, while no differences were found for total PA, VPA and SB.

235 Both age groups (<65 and ≥65 years) underestimated SB and MPA, and overestimated LPA,  
236 VPA and total PA when using the PAFQ. Participants aged <65 years underestimated MPA and  
237 overestimated LPA and VPA to a larger extent than participants aged ≥65 years. Participants aged ≥65  
238 years underestimated SB to a larger extent than participants aged <65 years, while no differences were  
239 found for total PA.

240 Both BMI groups (low and high) underestimated SB and MPA, and overestimated LPA, VPA and  
241 total PA when using the PAFQ. No differences in over- or underestimation were found between the  
242 groups.

243 Multivariate linear regression including gender, age and BMI groups showed that the high BMI  
244 group overestimated LPA to a larger extent than low BMI group, while no differences were found for  
245 total PA, MPA, VPA and SB (**Supplementary table 4**).

## 246 **DISCUSSION**

247 In this study comparing levels of PA measured with the PAFQ to activity measured with  
248 accelerometers, we observed that the PAFQ overestimated all PA levels while underestimating SB. Our  
249 findings also showed moderate overall correlations and concordance coefficients between the PAFQ  
250 and accelerometry data for total PA and SB. Differences in over- or underestimation were found  
251 between gender for LPA, MPA and MVPA, while between the age groups differences in over- or

252 underestimation were found for all levels of activity, except total PA. No differences in over- or  
253 underestimation were found between the BMI groups.

#### 254 *Comparison with previous literature*

255 A systematic review identified 100 different PA questionnaires with their respective validity  
256 against objective measures [37]. For PA, median correlation coefficients (0.25 to 0.41) were  
257 comparable to our findings (0.171 to 0.387). For SB, a median Spearman correlation of 0.12 was  
258 reported across all questionnaires between reported SB and inactivity calculated from objective  
259 measures, which was lower than in our study (0.370 to 0.387). They also found that newly developed  
260 physical activity questionnaires do not seem to perform better than existing ones. An explanation for  
261 the higher correlation of SB in our study might be that the PAFQ was developed with a focus on low  
262 intensity activities which otherwise may have been overlooked as important contributors to energy  
263 output [17]. At the development of the questionnaire, about 50 percent of the total energy  
264 expenditure was spent sleeping, sitting quietly, eating, and office work was the most important work  
265 related activity [17]. In addition, the GENEActiv accelerometer is shown to have a good validity for  
266 measuring adult sedentary time. A study comparing the GENEActiv accelerometer with an activPAL  
267 device estimating total sedentary time during waking hours reported an Intraclass Correlation  
268 Coefficient of 0.80 (95% CI: 0.68-0.88) [38].

269 The IPAQ (International Physical Activity Questionnaire) has been widely used to assess PA. A  
270 recent review summarized 23 validation studies of the short form of the IPAQ (IPAQ-SF) and showed  
271 poor correlations when compared with objective measurements [39]. The correlations ranged from  
272 0.09 to 0.39 for total PA, which is comparable to the findings in our study (0.373 to 0.387). Additionally,  
273 in agreement with our study, participants tended to report more PA with the IPAQ-SF than as assessed  
274 by the accelerometer. Over-reporting of PA remains a key limitation of most self-reported measures  
275 of PA [28] and is often due to misreporting of frequency, intensity and/or duration of activities [40].

276 Factors contributing to misreporting are social desirability and recall bias, which can be influenced by  
277 population characteristics such as gender, age and health status [41, 42].

278 In our study, results from the Bland-Altman plots showed that the differences between the  
279 PAFQ and accelerometry data increased with increasing time spent in all types of PA, similar to what  
280 has been seen in other studies [43, 44]. This suggests that the more time spent in each activity level,  
281 the higher the under- or overestimation. Therefore, the PAFQ might be a good estimator of activity for  
282 individuals with average time spent in each activity level, while for individuals that spent more time in  
283 a specific level of PA the PAFQ might lead to considerable overestimation compared to accelerometers.

284 Results from our study showed that the differences between PAFQ and accelerometer data for  
285 SB, VPA and total PA were generally similar for men and women. However, women overestimated LPA  
286 and underestimated MPA to a larger extent than men. Women tend to engage more in light and  
287 moderate PA, which are the most challenging types of activity to recall because they are most  
288 dominant in daily life as, for example, in household activities [45]. In our study, participants aged  $\geq 65$   
289 years underestimated SB to a larger extent than participants aged  $< 65$  years. This is similar to results  
290 from another study, comparing the IPAQ with accelerometer measurements among 1751 adults [44].  
291 Possible explanations is that elderly people are more likely to engage in activities that are most  
292 inaccurately assessed by questionnaires [46]. No differences in under- or overestimation were found  
293 between BMI groups, which is similar to findings in other studies [44, 47]. This is important as it has  
294 been suggested that obese people tend to overestimate PA due to social desirability [48, 49]. In  
295 summary the differences between PAFQ and accelerometer are similar in both genders and BMI  
296 groups for SB and total PA, and in the age groups for total PA only. Conversely, the differences between  
297 PAFQ and accelerometer in both genders and age groups are different for specific levels of PA, which  
298 might lead to differential estimations according to individual characteristics.

299 The PAFQ was developed in Geneva, Switzerland on the basis of a population survey using an  
300 approach similar to that proposed by Block et al. [50] for food frequency questionnaires [17]. The data

301 obtained from 24-hour recalls in the target population were used to establish a list of the major  
302 contributors in order to explain 95 percent of the energy expended by the total sample and by the  
303 male and female subsamples [17]. Therefore, activities that are typically related to Switzerland (e.g.  
304 Alpine skiing, stacking wood or angling) were captured in the questionnaire. The differences that were  
305 found between the questionnaire and the accelerometer could not be the result of typical Swiss  
306 activities that were missing in the questionnaire.

### 307 *Implications for public health*

308         The findings of our study may have implications for current and future practice on the  
309 measurement of PA. The PAFQ showed similar correlations and concordance with accelerometer  
310 measurements as found in similar studies validating other PA questionnaires. These findings suggest  
311 that the PAFQ is as valid as other questionnaires in SB and PA estimation. However, the Bland-Altman  
312 plots showed that the longer the time spent in a PA level, the higher the overestimation in the PAFQ  
313 compared to accelerometer. Hence, active people as assessed by PAFQ might be less active than they  
314 claim, and the associations between PA and health as obtained by questionnaires might actually be  
315 valid to lesser time spent in PA levels than thought, due to the overestimation of PA in the active  
316 individuals. In addition, under- or overestimation appears to differ between genders and age groups  
317 for different levels of PA, but not between BMI groups. Results from questionnaires might need either  
318 stratification, or adjustment on gender and age.

319         Questionnaires and accelerometers measure physical activity through different perspectives.  
320 The accelerometer is increasingly used in current research and designed to objectively measure the  
321 intensity and duration of activity and their results are comparable irrespective of the device used [51].  
322 However, they also have limitations. Depending on the attachment site of the hip or the wrist, they  
323 measure mainly lower or upper body movement, respectively [7]. Accelerometers also do not capture  
324 information on body posture (i.e. sitting or standing still) or whether a person is carrying weight.  
325 Moreover, they cannot capture the context in which the activities take place and they cannot

326 distinguish between types of activities. The questionnaire, on the other hand, is reliable on an  
327 individuals's answering ability but able to capture the context and type of activity, which is a major  
328 strength of physical activity questionnaires. Considering their advantages and disadvantages,  
329 questionnaires and accelerometers should be considered as complementary tools rather than a  
330 replacement for one another. Whenever possible, future studies should use both measurement  
331 methods in order to obtain comprehensive information of individual and population SB and PA levels.

### 332 *Strengths and limitations*

333 One of the major strengths of our study is that we took into account the differences between  
334 gender, age and BMI when comparing activity measured by the PAFQ and accelerometer. In addition,  
335 we compared SB, four different levels of PA and total PA. Another strength is our large sample size.  
336 Most validation studies summarized in the review by Helmerhorst et al [37] included fewer than 300  
337 participants, while our study comprised 1752 participants. Moreover, the use of a waterproof wrist-  
338 worn accelerometer ensured high compliance. Participants were requested to wear the accelerometer  
339 for 14 consecutive days, which far exceeds the 3-5 days required to assess a daily estimate of the  
340 individual's habitual activity [52]. Finally, the sensitivity analyses whereby participants with extreme  
341 sleep durations were excluded provided consistent findings.

342 The findings of this study must be considered in the context of some limitations. First, the SB  
343 and PA estimates from PAFQ and accelerometer were not obtained at the same period. Participants  
344 filled in the questionnaire and brought it to the study centre, where they were given the accelerometer  
345 for 14 consecutive days. Nevertheless, it has been reported that physical activity at middle age tend to  
346 be relatively constant overtime [53]. Therefore the effect might not be of a large magnitude nor would  
347 it be expected to differ by levels of PA. Second, included participants were younger than excluded  
348 participants, which might affect the generalizability among the elderly. Furthermore, the findings of  
349 this study are based on the difference between the PAFQ and the GENEActiv accelerometer. As such,  
350 our findings might not be generalizable to other questionnaires, since other questionnaires measure

351 PA in a different way. Finally, it is reported that the GENEActiv accelerometer tends to overestimate  
352 PA and underestimate SB [54]. Therefore, the differences observed in this study might actually be  
353 underestimated.

#### 354 *Conclusion*

355 The present study shows large variations between the PAFQ and accelerometer measured PA  
356 and SB, and the difference increased with more time spent in PA. Sex and age, but not BMI, influenced  
357 these variations. Questionnaires and accelerometers measure activity through different perspectives.  
358 Although there is a certain degree of comparability, they should be considered as complementary tools  
359 to obtain comprehensive information of individual and population physical activity levels.

#### 360 **DECLARATIONS**

##### 361 *Ethical approval and consent to participate*

362 The institutional Ethics Committee of the University of Lausanne, which afterwards became  
363 the Ethics Commission of Canton Vaud ([www.cer-vd.ch](http://www.cer-vd.ch)) approved the baseline CoLaus study  
364 (reference 16/03, decisions of 13<sup>th</sup> January and 10<sup>th</sup> February 2003). The approval was renewed for the  
365 first (reference 33/09, decision of 23<sup>rd</sup> February 2009) and the second (reference 26/14, decision of  
366 11<sup>th</sup> March 2014) follow-ups. The full decisions of the CER-VD can be obtained from the authors upon  
367 request. The study was performed in agreement with the Helsinki declaration and its former  
368 amendments, and in accordance with the applicable Swiss legislation. All participants gave their signed  
369 informed consent before entering the study.

##### 370 *Availability of data and material*

371 Due to the sensitivity of the data and the lack of consent for online posting, individual data  
372 cannot be made accessible. Only metadata will be made available in digital repositories. Metadata  
373 requests can also be performed via the study website [www.colaus-psycolaus.ch](http://www.colaus-psycolaus.ch)

374 *Competing interest*

375           The authors report no conflict of interest.

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380 *Authors contributions*

381           SV made part of the statistical analyses and wrote most of the article; CG collected; PMV made  
382 part of the statistical analysis and wrote part of the article; OHF wrote part of the article; CG, PMV,  
383 OHF, IG and AB revised the article for important intellectual content. PMV had full access to the data  
384 and is the guarantor of the study.

385

386



387 **REFERENCES**

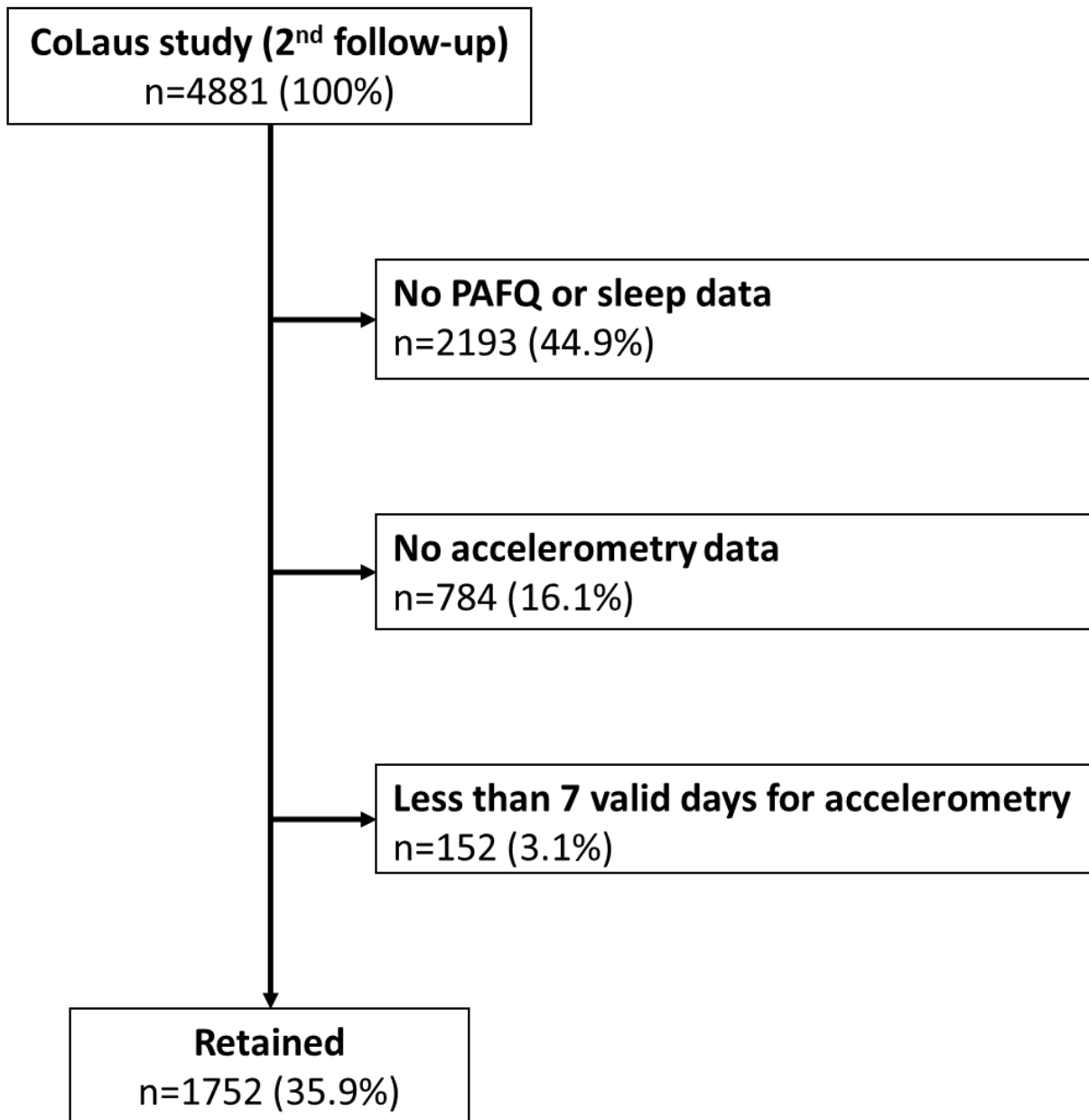
- 388 [1] F.W. Booth, C.K. Roberts, M.J. Laye, Lack of exercise is a major cause of chronic diseases,  
389 *Comprehensive Physiology* 2(2) (2012) 1143-1211.
- 390 [2] World Health Organisation, *Global recommendations on physical activity for health*, Geneva; 2010.
- 391 [3] D. Ndahimana, E.K. Kim, *Measurement Methods for Physical Activity and Energy Expenditure: a*  
392 *Review*, *Clin Nutr Res* 6(2) (2017) 68-80.
- 393 [4] L.G. Sylvia, E.E. Bernstein, J.L. Hubbard, L. Keating, E.J. Anderson, *A Practical Guide to Measuring*  
394 *Physical Activity*, *Journal of the Academy of Nutrition and Dietetics* 114(2) (2014) 199-208.
- 395 [5] S. Skender, J. Ose, J. Chang-Claude, M. Paskow, B. Brühmann, E.M. Siegel, K. Steindorf, C.M. Ulrich,  
396 *Accelerometry and physical activity questionnaires - a systematic review*, *BMC Public Health* 16 (2016)  
397 515.
- 398 [6] J.E. Sasaki, K.S. da Silva, B. Gonçalves Galdino da Costa, D. John, Chapter 2 - Measurement of  
399 *Physical Activity Using Accelerometers*, in: J.K. Luiselli, A.J. Fischer (Eds.), *Computer-Assisted and Web-*  
400 *Based Innovations in Psychology, Special Education, and Health*, Academic Press, San Diego, 2016, pp.  
401 33-60.
- 402 [7] I.M. Lee, E.J. Shiroma, *Using Accelerometers to Measure Physical Activity in Large-Scale*  
403 *Epidemiologic Studies: Issues and Challenges*, *British journal of sports medicine* 48(3) (2014) 197-201.
- 404 [8] K. Kowalski, R. Rhodes, P.-J. Naylor, H. Tuokko, S. MacDonald, *Direct and indirect measurement of*  
405 *physical activity in older adults: a systematic review of the literature*, *The international journal of*  
406 *behavioral nutrition and physical activity* 9 (2012) 148-148.
- 407 [9] S.A. Prince, K.B. Adamo, M.E. Hamel, J. Hardt, S. Connor Gorber, M. Tremblay, *A comparison of*  
408 *direct versus self-report measures for assessing physical activity in adults: a systematic review*, *The*  
409 *international journal of behavioral nutrition and physical activity* 5 (2008) 56.
- 410 [10] M.P. Buman, E.A. Winkler, J.M. Kurka, E.B. Hekler, C.M. Baldwin, N. Owen, B.E. Ainsworth, G.N.  
411 Healy, P.A. Gardiner, *Reallocating time to sleep, sedentary behaviors, or active behaviors: associations*  
412 *with cardiovascular disease risk biomarkers, NHANES 2005-2006*, *American journal of epidemiology*  
413 179(3) (2014) 323-34.
- 414 [11] G.N. Healy, C.E. Matthews, D.W. Dunstan, E.A. Winkler, N. Owen, *Sedentary time and cardio-*  
415 *metabolic biomarkers in US adults: NHANES 2003-06*, *European heart journal* 32(5) (2011) 590-7.
- 416 [12] G.N. Healy, K. Wijndaele, D.W. Dunstan, J.E. Shaw, J. Salmon, P.Z. Zimmet, N. Owen, *Objectively*  
417 *measured sedentary time, physical activity, and metabolic risk: the Australian Diabetes, Obesity and*  
418 *Lifestyle Study (AusDiab)*, *Diabetes care* 31(2) (2008) 369-71.
- 419 [13] Q. Qi, G. Strizich, G. Merchant, D. Sotres-Alvarez, C. Buelna, S.F. Castaneda, L.C. Gallo, J. Cai, M.D.  
420 Gellman, C.R. Isasi, A.E. Moncrieff, L. Sanchez-Johnsen, N. Schneiderman, R.C. Kaplan, *Objectively*  
421 *Measured Sedentary Time and Cardiometabolic Biomarkers in US Hispanic/Latino Adults: The Hispanic*  
422 *Community Health Study/Study of Latinos (HCHS/SOL)*, *Circulation* 132(16) (2015) 1560-9.
- 423 [14] S. Scholes, N. Coombs, Z. Pedisic, J.S. Mindell, A. Bauman, A.V. Rowlands, E. Stamatakis, *Age- and*  
424 *sex-specific criterion validity of the health survey for England Physical Activity and Sedentary Behavior*  
425 *Assessment Questionnaire as compared with accelerometry*, *American journal of epidemiology*  
426 179(12) (2014) 1493-502.
- 427 [15] F.A. Barwais, T.F. Cuddihy, T. Washington, L.M. Tomson, E. Brymer, *Development and validation*  
428 *of a new self-report instrument for measuring sedentary behaviors and light-intensity physical activity*  
429 *in adults*, *Journal of physical activity & health* 11(6) (2014) 1097-104.
- 430 [16] S.R. Gomersall, T.G. Pavey, B.K. Clark, A. Jasman, W.J. Brown, *Validity of a Self-Report Recall Tool*  
431 *for Estimating Sedentary Behavior in Adults*, *Journal of physical activity & health* 12(11) (2015) 1485-  
432 91.
- 433 [17] M. Bernstein, D. Sloutskis, S. Kumanyika, A. Sparti, Y. Schutz, A. Morabia, *Data-based approach for*  
434 *developing a physical activity frequency questionnaire*, *American journal of epidemiology* 147(2)  
435 (1998) 147-54.

- 436 [18] M.C. Costanza, S. Beer-Borst, A. Morabia, Achieving energy balance at the population level  
437 through increases in physical activity, *Am J Public Health* 97(3) (2007) 520-525.
- 438 [19] Y. Henchoz, F. Bastardot, I. Guessous, J.-M. Theler, J. Dudler, P. Vollenweider, A. So, Physical  
439 activity and energy expenditure in rheumatoid arthritis patients and matched controls, *Rheumatology*  
440 51(8) (2012) 1500-1507.
- 441 [20] P. Marques-Vidal, G. Waeber, P. Vollenweider, I. Guessous, Socio-demographic and lifestyle  
442 determinants of dietary patterns in French-speaking Switzerland, 2009-2012, *BMC Public Health* 18(1)  
443 (2018) 131.
- 444 [21] M. Aligisakis, P. Marques-Vidal, I. Guessous, P. Vollenweider, Did Dumbo suffer a heart attack?  
445 independent association between earlobe crease and cardiovascular disease, *BMC cardiovascular*  
446 *disorders* 16 (2016) 17-17.
- 447 [22] S. Khalatbari-Soltani, F. Imamura, S. Brage, E. De Lucia Rolfe, S.J. Griffin, N.J. Wareham, P.  
448 Marques-Vidal, N.G. Forouhi, The association between adherence to the Mediterranean diet and  
449 hepatic steatosis: cross-sectional analysis of two independent studies, the UK Fenland Study and the  
450 Swiss CoLaus Study, *BMC Med* 17(1) (2019) 19-19.
- 451 [23] I. Guessous, M. Bochud, J.-M. Theler, J.-M. Gaspoz, A. Pechère-Bertschi, 1999-2009 Trends in  
452 prevalence, unawareness, treatment and control of hypertension in Geneva, Switzerland, *PloS one* 7(6)  
453 (2012) e39877-e39877.
- 454 [24] M. Firmann, V. Mayor, P.M. Vidal, M. Bochud, A. Pecoud, D. Hayoz, F. Paccaud, M. Preisig, K.S.  
455 Song, X. Yuan, T.M. Danoff, H.A. Stirnadel, D. Waterworth, V. Mooser, G. Waeber, P. Vollenweider, The  
456 CoLaus study: a population-based study to investigate the epidemiology and genetic determinants of  
457 cardiovascular risk factors and metabolic syndrome, *BMC cardiovascular disorders* 8 (2008) 6.
- 458 [25] A. Morabia, M. Bernstein, S. Heritier, A. Ylli, Community-based surveillance of cardiovascular risk  
459 factors in Geneva: methods, resulting distributions, and comparisons with other populations, *Prev Med*  
460 26(3) (1997) 311-9.
- 461 [26] R. Shephard, A. Vuillemin, Limits to the measurement of habitual physical activity by  
462 questionnaires, *British journal of sports medicine* 37(3) (2003) 197-206.
- 463 [27] G. Rait, A. Fletcher, L. Smeeth, C. Brayne, S. Stirling, M. Nunes, E. Breeze, E.S. Ng, C.J. Bulpitt, D.  
464 Jones, A.J. Tulloch, Prevalence of cognitive impairment: results from the MRC trial of assessment and  
465 management of older people in the community, *Age and ageing* 34(3) (2005) 242-8.
- 466 [28] J.F. Sallis, B.E. Saelens, Assessment of physical activity by self-report: status, limitations, and future  
467 directions, *Research quarterly for exercise and sport* 71 Suppl 2 (2000) 1-14.
- 468 [29] M.S. Bernstein, M.C. Costanza, A. Morabia, Association of physical activity intensity levels with  
469 overweight and obesity in a population-based sample of adults, *Preventive Medicine* 38(1) (2004) 94-  
470 104.
- 471 [30] B.E. Ainsworth, W.L. Haskell, A.S. Leon, D.R. Jacobs, Jr., H.J. Montoye, J.F. Sallis, R.S. Paffenbarger,  
472 Jr., Compendium of physical activities: classification of energy costs of human physical activities,  
473 *Medicine and science in sports and exercise* 25(1) (1993) 71-80.
- 474 [31] B.E. Ainsworth, W.L. Haskell, M.C. Whitt, M.L. Irwin, A.M. Swartz, S.J. Strath, W.L. O'Brien, D.R.  
475 Bassett, Jr., K.H. Schmitz, P.O. Emplaincourt, D.R. Jacobs, Jr., A.S. Leon, Compendium of physical  
476 activities: an update of activity codes and MET intensities, *Medicine and science in sports and exercise*  
477 32(9 Suppl) (2000) S498-504.
- 478 [32] D.W. Esliger, A.V. Rowlands, T.L. Hurst, M. Catt, P. Murray, R.G. Eston, Validation of the GENE  
479 Accelerometer, *Medicine and science in sports and exercise* 43(6) (2011) 1085-93.
- 480 [33] C. Gubelmann, P. Vollenweider, P. Marques-Vidal, Of weekend warriors and couch potatoes:  
481 Socio-economic determinants of physical activity in Swiss middle-aged adults, *Prev Med* 105 (2017)  
482 350-355.
- 483 [34] L.I. Lin, A concordance correlation coefficient to evaluate reproducibility, *Biometrics* 45(1) (1989)  
484 255-68.
- 485 [35] G.B. McBride, A proposal for strength-of-agreement criteria for Lin's concordance correlation  
486 coefficient, 2005.

- 487 [36] D.E. Hinkle, W. Wiersma, S.G. Jurs, *Applied statistics for the behavioral sciences*, (1988).
- 488 [37] H.J.F. Helmerhorst, S. Brage, J. Warren, H. Besson, U. Ekelund, A systematic review of reliability  
489 and objective criterion-related validity of physical activity questionnaires, *The international journal of*  
490 *behavioral nutrition and physical activity* 9 (2012) 103-103.
- 491 [38] T.G. Pavey, S.R. Gomersall, B.K. Clark, W.J. Brown, The validity of the GENEActiv wrist-worn  
492 accelerometer for measuring adult sedentary time in free living, *Journal of science and medicine in*  
493 *sport* 19(5) (2016) 395-9.
- 494 [39] P.H. Lee, D.J. Macfarlane, T.H. Lam, S.M. Stewart, Validity of the international physical activity  
495 questionnaire short form (IPAQ-SF): A systematic review, *The international journal of behavioral*  
496 *nutrition and physical activity* 8 (2011) 115-115.
- 497 [40] L.B. Rasmussen, J. Matthiessen, A. Biloft-Jensen, I. Tetens, Characteristics of misreporters of  
498 dietary intake and physical activity, *Public health nutrition* 10(3) (2007) 230-7.
- 499 [41] S.A. Adams, C.E. Matthews, C.B. Ebbeling, C.G. Moore, J.E. Cunningham, J. Fulton, J.R. Hebert, The  
500 effect of social desirability and social approval on self-reports of physical activity, *American journal of*  
501 *epidemiology* 161(4) (2005) 389-98.
- 502 [42] S. Sabia, V.T. van Hees, M.J. Shipley, M.I. Trenell, G. Hagger-Johnson, A. Elbaz, M. Kivimaki, A.  
503 Singh-Manoux, Association between questionnaire- and accelerometer-assessed physical activity: the  
504 role of sociodemographic factors, *American journal of epidemiology* 179(6) (2014) 781-90.
- 505 [43] S.E. Bonn, P. Bergman, Y. Trolle Lagerros, A. Sjölander, K. Bälter, A Validation Study of the Web-  
506 Based Physical Activity Questionnaire Active-Q Against the GENE Accelerometer, *JMIR Research*  
507 *Protocols* 4(3) (2015) e86.
- 508 [44] S.M. Dyrstad, B.H. Hansen, I.M. Holme, S.A. Anderssen, Comparison of self-reported versus  
509 accelerometer-measured physical activity, *Med Sci Sports Exerc* 46(1) (2014) 99-106.
- 510 [45] C.M. Friedenreich, K.S. Courneya, H.K. Neilson, C.E. Matthews, G. Willis, M. Irwin, R. Troiano, R.  
511 Ballard-Barbash, Reliability and validity of the Past Year Total Physical Activity Questionnaire, *American*  
512 *journal of epidemiology* 163(10) (2006) 959-70.
- 513 [46] R.A. Washburn, A.M. Jette, C.A. Janney, Using Age-Neutral Physical Activity Questionnaires in  
514 Research with the Elderly, *Journal of Aging and Health* 2(3) (1990) 341-356.
- 515 [47] U. Ekelund, H. Sepp, S. Brage, W. Becker, R. Jakes, M. Hennings, N.J. Wareham, Criterion-related  
516 validity of the last 7-day, short form of the International Physical Activity Questionnaire in Swedish  
517 adults, *Public health nutrition* 9(2) (2006) 258-65.
- 518 [48] M.S. Buchowski, K.M. Townsend, K.Y. Chen, S.A. Acra, M. Sun, Energy expenditure determined by  
519 self-reported physical activity is related to body fatness, *Obesity research* 7(1) (1999) 23-33.
- 520 [49] C. Howitt, S. Brage, I.R. Hambleton, K. Westgate, T.A. Samuels, A.M. Rose, N. Unwin, A cross-  
521 sectional study of physical activity and sedentary behaviours in a Caribbean population: combining  
522 objective and questionnaire data to guide future interventions, *BMC public health* 16(1) (2016) 1036.
- 523 [50] G. Block, A.M. Hartman, C.M. Dresser, M.D. Carroll, J. Gannon, L. Gardner, A data-based approach  
524 to diet questionnaire design and testing, *American journal of epidemiology* 124(3) (1986) 453-69.
- 525 [51] A.V. Rowlands, E.M. Mirkes, T. Yates, S. Clemes, M. Davies, K. Khunti, C.L. Edwardson,  
526 Accelerometer-assessed Physical Activity in Epidemiology: Are Monitors Equivalent?, *Medicine and*  
527 *science in sports and exercise* 50(2) (2018) 257-265.
- 528 [52] S.G. Trost, K.L. McIver, R.R. Pate, Conducting accelerometer-based activity assessments in field-  
529 based research, *Med Sci Sports Exerc* 37(11 Suppl) (2005) S531-43.
- 530 [53] C.J. Caspersen, M.A. Pereira, K.M. Curran, Changes in physical activity patterns in the United  
531 States, by sex and cross-sectional age, *Med Sci Sports Exerc* 32(9) (2000) 1601-9.
- 532 [54] M.E. Rosenberger, M.P. Buman, W.L. Haskell, M.V. McConnell, L.L. Carstensen, Twenty-four Hours  
533 of Sleep, Sedentary Behavior, and Physical Activity with Nine Wearable Devices, *Medicine and science*  
534 *in sports and exercise* 48(3) (2016) 457-65.

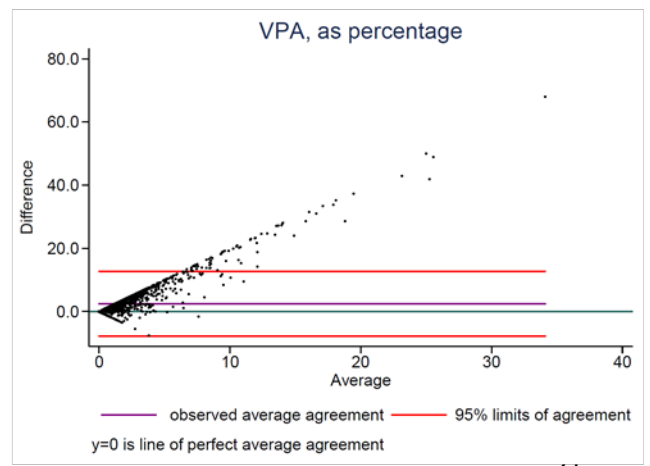
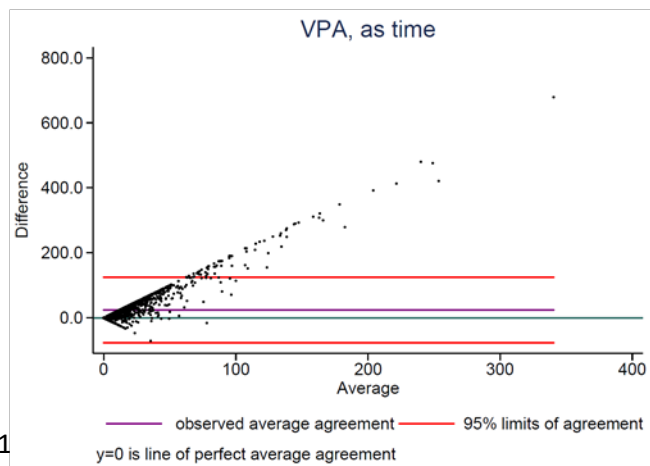
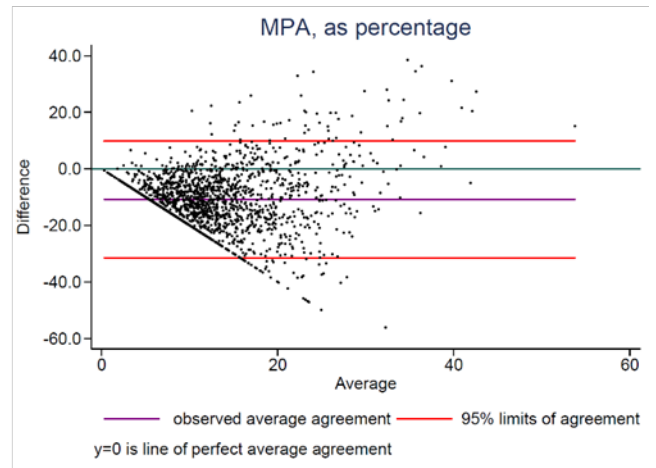
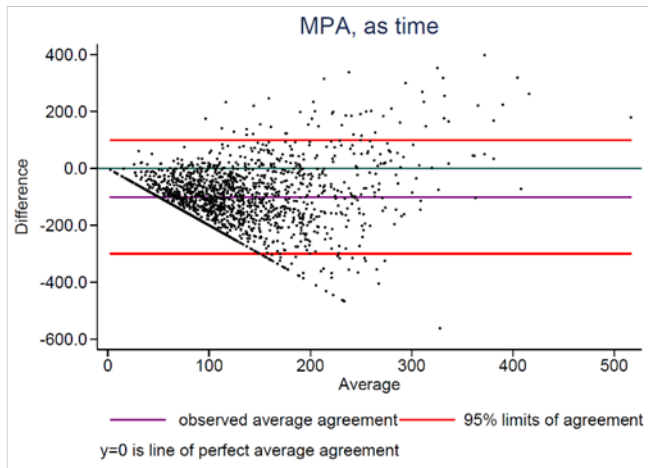
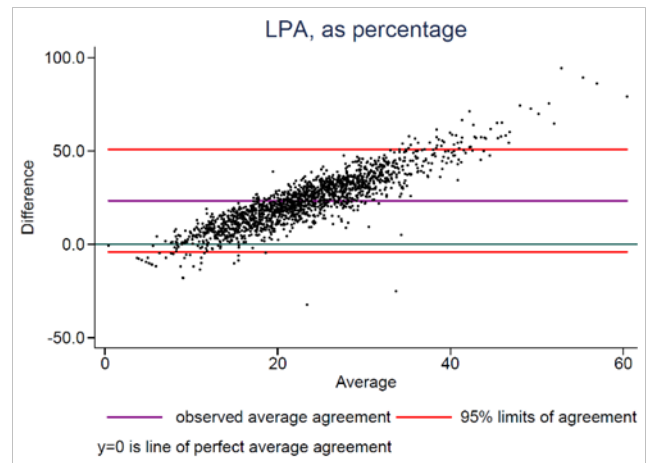
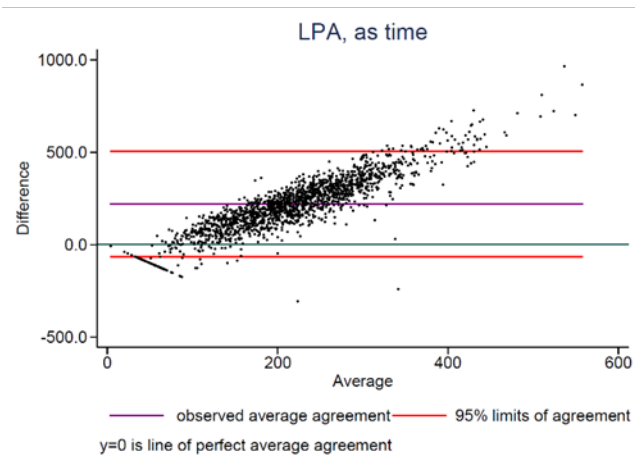
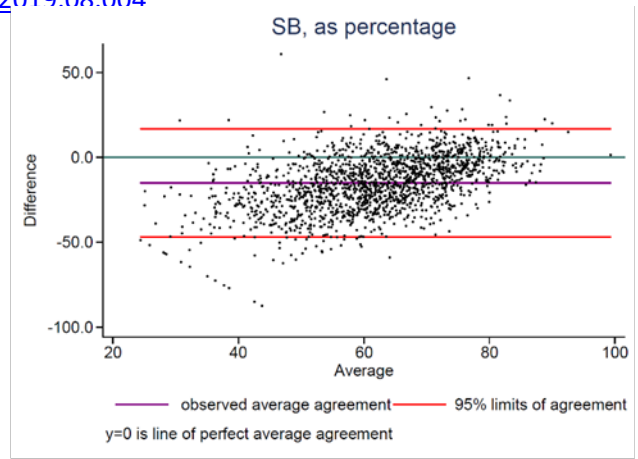
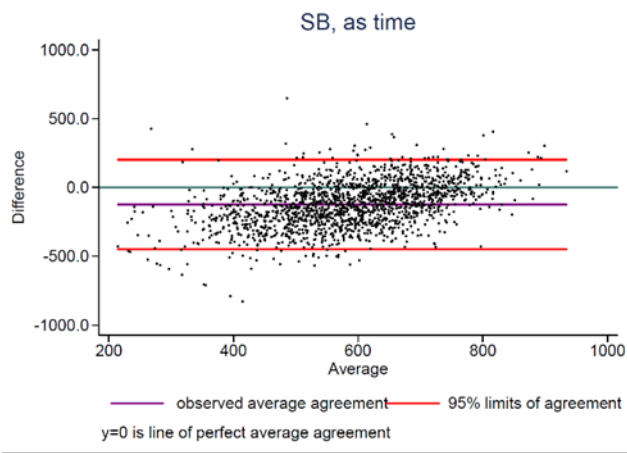
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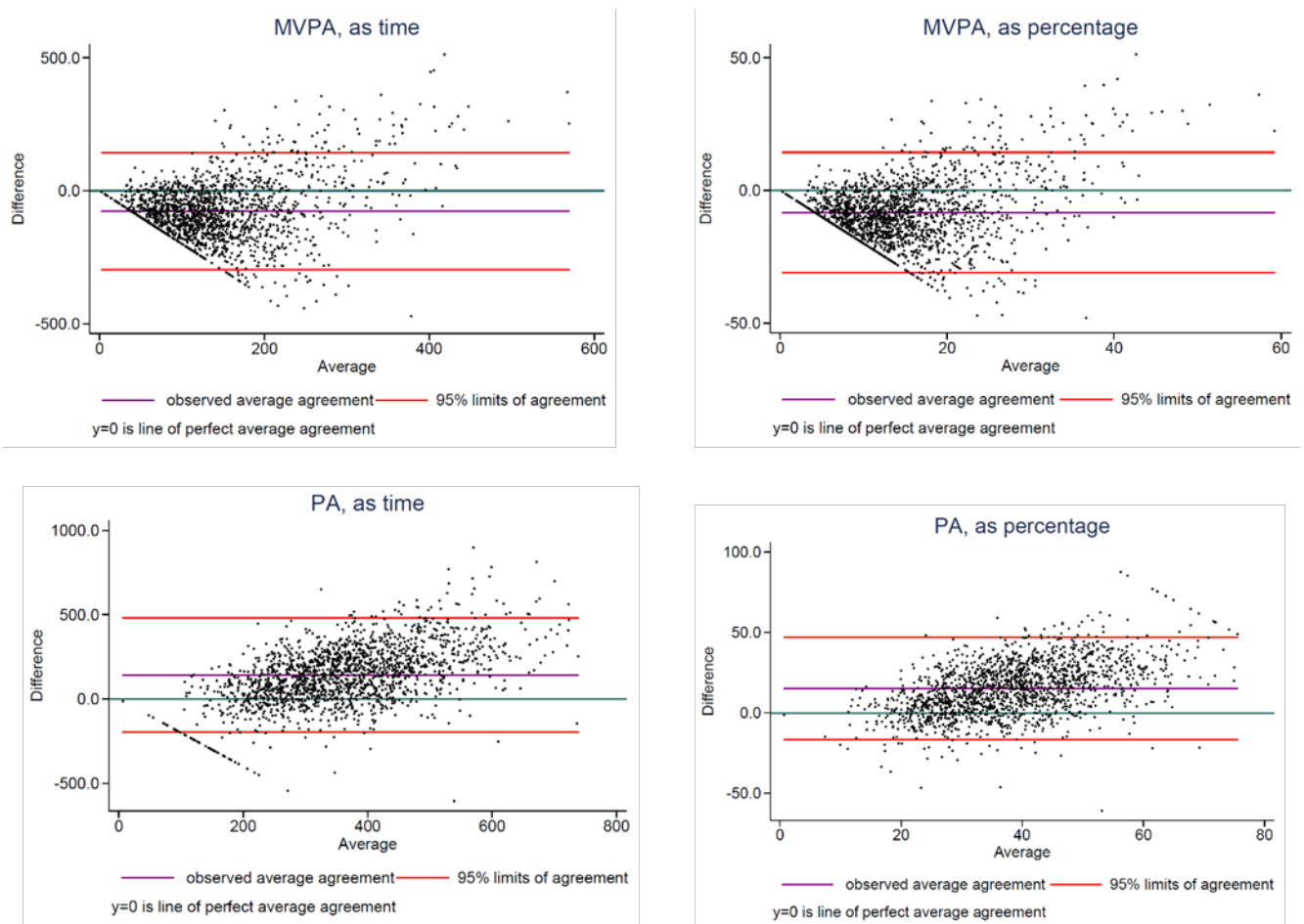
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**Figure 1.** Flowchart of participants





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544 **Figure 2.** Bland-Altman plots as time and percentage of time for SB, LPA, MPA, VPA, MVPA, and total

545 PA. x-axis depicts the average of the PAFQ and accelerometer; y-axis depicts difference between

546 PAFQ and accelerometer

547 SB, sedentary behaviour; LPA, light physical activity; MPA, moderate physical activity; MVPA,

548 moderate-to-vigorous physical activity; PA, physical activity.

**Table 1.** Activity levels according to PAFQ and accelerometer in 1752 participants.

	PAFQ	Accelerometer	Difference
As time (minutes/day)			
Sedentary behaviour	524 [410; 645]	652 [578; 724]	-123 [-238; -14]
Light PA	180 [119; 254]	106 [84; 130]	72 [12; 141]
Moderate PA	186 [120; 264.5]	162 [119; 219.5]	22.5 [-46; 100]
Vigorous PA	16 [0; 46]	2 [0; 5]	13 [-1; 41]
Moderate + vigorous PA	213 [143.5; 315]	166 [121.5; 226]	46 [-25; 141]
Total PA	424 [312; 541]	277 [215.5; 354]	143 [34.5; 249]
As % of time			
Sedentary behaviour	54.8 [42.9; 66.7]	70.4 [62.7; 76.8]	-14.7 [-25.7; -4.1]
Light PA	18.8 [12.6; 26.3]	11.3 [9.2; 13.7]	7.5 [1.1; 14.6]
Moderate PA	19.2 [12.7; 27.8]	17.5 [12.8; 23.4]	1.7 [-5.3; 10.1]
Vigorous PA	1.8 [0; 4.7]	0.2 [0; 0.6]	1.3 [-0.1; 4.2]
Moderate + vigorous PA	22.3 [14.8; 33.0]	18.1 [13.0; 24.2]	4.1 [-3.3; 14.2]
Total PA	45.2 [33.3; 57.1]	29.5 [23.2; 37.3]	14.7 [4.1; 25.7]

PA, physical activity; PAFQ, physical activity frequency questionnaire. Difference indicates PAFQ – accelerometer. Results are expressed as median [interquartile range]. Between-group comparisons are performed using Wilcoxon signed-rank test. All differences are significant at  $p < 0.001$ .

**Table 2.** Correlation of activity levels between PAFQ and accelerometer.

	<b>Spearman</b>	<b>Lin</b>
As time (minutes/day)		
Sedentary behaviour	0.370 (0.325 – 0.409)	0.238 (0.208 – 0.268)
Light PA	0.205 (0.157 – 0.248)	0.074 (0.055 – 0.093)
Moderate PA	0.285 (0.241 – 0.331)	0.239 (0.201 – 0.276)
Vigorous PA	0.171 (0.124 – 0.221)	0.044 (0.035 – 0.053)
Moderate + vigorous PA	0.329 (0.289 – 0.372)	0.250 (0.218 – 0.282)
Total PA	0.373 (0.331 – 0.417)	0.209 (0.183 – 0.236)
As % of time		
Sedentary behaviour	0.387 (0.346 – 0.426)	0.218 (0.192 – 0.244)
Light PA	0.215 (0.165 – 0.260)	0.075 (0.057 – 0.094)
Moderate PA	0.279 (0.233 – 0.325)	0.239 (0.201 – 0.277)
Vigorous PA	0.171 (0.126 – 0.217)	0.045 (0.036 – 0.055)
Moderate + vigorous PA	0.326 (0.283 – 0.367)	0.254 (0.221 – 0.286)
Total PA	0.387 (0.348 – 0.430)	0.218 (0.192 – 0.244)

PA, physical activity. Results are expressed as Spearman rank correlation or Lin concordance coefficients (95% confidence intervals). For Spearman correlation coefficients, 95% confidence intervals are bootstrapped and bias-corrected values are presented. All coefficients are statistically significant at  $p < 0.001$ . Results for sedentary behaviour and total PA expressed as % of time are similar as values are complementary.



**Table 3.** Associations of difference in time spent in sedentary behaviour and different levels of physical activity between PAFQ and accelerometer with gender, age and body mass index groups.

	Gender (men vs. women)		Age (<65 vs. ≥65 years)		BMI (low vs. high)	
	Constant	Coefficient	Constant	Coefficient	Constant	Coefficient
As time (mins/day)						
Sedentary behaviour	-130.7*	12.7 (-3.0; 28.5)	-113.9*	-32.4 (-49.1; -15.6)*	-117.2*	-13.0 (-28.8; 2.9)
Light PA	240.9*	-43.5 (-57.0; -30.1)*	227.4*	-24.5 (-39.0; -10.0)*	216.5*	5.3 (-8.5; 19.0)
Moderate PA	-118.6*	36.7 (27.3; 46.1)*	-111.6*	34.3 (24.6; 44.4)*	-102.7*	4.0 (-5.7; 13.6)
Vigorous PA	21.5*	4.6 (-0.2; 9.5)	25.9*	-6.5 (-11.7; -1.4)*	23.5*	0.6 (-4.2; 5.5)
Moderate + vigorous PA	-97.0*	41.4 (31.0; 51.7)*	-85.7*	27.8 (16.6; 39.0)*	-79.3*	4.6 (-6.0; 15.2)
Total PA	143.9*	-2.2 (-18.4; 14.0)	141.7*	3.3 (-14.0; 20.6)	137.3*	9.9 (-6.4; 26.1)

BMI, body mass index; PA, physical activity; PAFQ, physical activity frequency questionnaire. Results are expressed as coefficients (95% confidence intervals). All coefficients marked with \* are statistically significant at  $p < 0.05$ . The categories of women, age <65 years and low BMI are considered as reference.

**Supplementary material****Supplementary table 1.** Characteristics of excluded and included participants.

	<b>Included (n=1752)</b>	<b>Excluded (n=3129)</b>	<b>p-value</b>
Female (%)	889 (50.7)	1800 (57.5)	< 0.001
Age (years)	60.5 ± 9.4	64.3 ± 10.8	< 0.001
Age groups (%)			< 0.001
<65	1183 (67.5)	1665 (53.2)	
≥65	569 (32.5)	1464 (46.8)	
Body mass index (kg/m <sup>2</sup> )	26.1 ± 4.6	26.6 ± 4.8	< 0.001
BMI categories (%)			< 0.001
Low	769 (43.9)	1088 (39.9)	
High	983 (56.1)	1641 (60.1)	

BMI, body mass index. Results are expressed as number of participants (column percentage) or as average ± standard deviation. Between-group comparisons are performed using chi-square for categorical variables or student's t-test for continuous variables. For BMI of excluded participants, number of participants does not add to 3129 due to the presence of missing values.

**Supplementary table 2.** Activity levels according to PAFQ and accelerometer, after exclusion of 40 participants with sleep time <4 or >10 hours/day (n = 1712)

	<b>PAFQ</b>	<b>Accelerometer</b>	<b>Difference</b>
	Median [IQR]	Median [IQR]	Median [IQR]
<b>As time (minutes/day)</b>			
Sedentary behaviour	526 [412; 648]	652 [578; 725]	-121 [-238; -12]
Light PA	181 [120; 254.5]	107 [84; 131]	73 [12; 142]
Moderate PA	187 [121; 267]	164 [120; 220]	22 [-47; 101]
Vigorous PA	16 [0; 46]	2 [0; 5]	13 [-1; 41]
Moderate + vigorous PA	213.5 [144; 317]	168.5 [123; 227]	46 [-25.5; 142]
Total PA	426 [314.5; 544]	278 [218; 355.5]	143.5 [34.5; 251.5]
<b>As % of time</b>			
Sedentary behaviour	54.8 [42.8; 66.7]	70.3 [62.6; 76.7]	-14.6 [-25.6; -4.1]
Light PA	18.8 [12.5; 26.4]	11.3 [9.2; 13.7]	7.5 [1.0; 14.6]
Moderate PA	19.2 [12.7; 27.8]	17.6 [12.9; 23.4]	1.6 [-5.3; 10.0]
Vigorous PA	1.8 [0; 4.8]	0.2 [0.1; 0.6]	1.4 [-0.1; 4.2]
Moderate + vigorous PA	22.3 [14.8; 33.0]	18.2 [13.1; 24.2]	4 [-3.4; 14.1]
Total PA	45.2 [33.4; 57.3]	29.7 [23.3; 37.4]	14.6 [4.1; 25.6]

PA, physical activity; PAFQ, physical activity frequency questionnaire. Results are expressed as median [interquartile range]. Between-group comparisons are performed using Wilcoxon signed-rank test. All differences are significant at  $p < 0.001$

**Supplementary table 3.** Correlation of activity levels between PAFQ and accelerometer, after exclusion of 40 participants with sleep time <4 or >10 hours/day excluded (n = 1712)

	<b>Spearman</b>	<b>Lin</b>
As time (minutes/day)		
Sedentary behaviour	0.373 (0.331 – 0.415)	0.240 (0.210 – 0.270)
Light PA	0.204 (0.156 – 0.249)	0.074 (0.054 – 0.093)
Moderate PA	0.282 (0.231 – 0.325)	0.234 (0.196 – 0.272)
Vigorous PA	0.169 (0.123 – 0.215)	0.044 (0.035 – 0.053)
Moderate + vigorous PA	0.326 (0.280 – 0.375)	0.246 (0.213 – 0.278)
Total PA	0.368 (0.324 – 0.410)	0.206 (0.179 – 0.232)
As % of time		
Sedentary behaviour	0.391 (0.347 – 0.430)	0.220 (0.193 – 0.246)
Light PA	0.216 (0.166 – 0.260)	0.076 (0.057 – 0.094)
Moderate PA	0.282 (0.239 – 0.326)	0.240 (0.201 – 0.278)
Vigorous PA	0.169 (0.122 – 0.214)	0.046 (0.036 – 0.055)
Moderate + vigorous PA	0.328 (0.283 – 0.373)	0.253 (0.220 – 0.286)
Total PA	0.391 (0.351 – 0.435)	0.219 (0.193 – 0.246)

PA, physical activity; PAFQ, physical activity frequency questionnaire. Results are expressed as Spearman rank correlation or Lin concordance coefficients (95% confidence intervals). For Spearman correlation coefficients, 95% confidence intervals are bootstrapped and bias-corrected values are presented. All coefficients are statistically significant at  $p < 0.001$ . Results for sedentary behaviour and total PA expressed as % of time are similar as values are complementary.

**Supplementary table 4.** Associations of difference in time spent in SB and different levels of PA between PAFQ and accelerometer with gender, age and BMI groups, with adjustment for each other.

	Constant	Gender (men vs. women)	Age (<65 vs. ≥65 years)	BMI (low vs. high)
As time (minutes/day)				
Sedentary behaviour	-114.1*	14.2 (-1.7; 30.1)	-30.8 (-47.7; -14.0)*	-13.0 (-29.1; 3.1)
Light PA	242.8*	-46.8 (-60.4; -33.1)*	-27.2 (-41.6; -12.8)*	15.2 (1.4; 29.0)*
Moderate PA	-128.2*	38.5 (29.1; 47.9)*	35.9 (26.0; 45.8)*	-5.3 (-14.8; 4.2)
Vigorous PA	23.5*	4.4 (-0.5; 9.3)	-6.4 (-11.6; -1.3)*	0.4 (-4.5; 5.3)
Moderate + vigorous PA	-104.6*	42.9 (32.5; 53.4)*	29.5 (18.4; 40.5)*	-4.9 (-15.4; 5.7)
Total PA	138.2*	-3.8 (-20.3; 12.6)	2.3 (-15.0; 19.6)	10.3 (-6.3; 26.9)

PA, physical activity; PAFQ, physical activity frequency questionnaire. Results are expressed as coefficients (95% confidence intervals). All coefficients marked with \* are statistically significant at  $p < 0.05$

**Additional file 1:** Categorization of the activities from the physical activity questionnaire

<b>Occupational activities</b>	<b>Category</b>
Office work, seated or standing (desk, PC, telephone, ...)	Sedentary
Writing at a black board, standing	Light
Housekeeping and cleaning (sweeping floors, vacuuming...)	Moderate
Cooking	Light
Sewing, ironing	Moderate
Washing, hanging out clothes	Light
Taking care of babies or toddlers	Moderate
Taking care of children calmly	Moderate
Carpentry, masonry, lock smith, handy work, electrician, etc.	Moderate
Heavy construction work (digging holes, carrying or pulling loads, etc.)	Vigorous
Auto mechanic	Moderate
Hand work in machine-tool, chemical, or electrical industry	Light
Warehouseman, storekeeper	Vigorous
Painting, decorating	Moderate
Laboratory work	Light
Gardening	Moderate
Harvesting fruits, vegetables, herbs	Moderate
Playing a musical instrument	Moderate
Ballroom or folk dancing	Moderate
<b>Walking and Driving at Work (during Office Hours)</b>	
Walking normally or walking slowly	Moderate
Walking quickly or walking uphill	Moderate
Walking while carrying or pulling a load	Vigorous
Climbing up stairs	Not coded
Driving a car or a truck	Light
<b>Eating and Personal grooming</b>	
Washing up (shower, bath, etc.), dressing, undressing	Sedentary
Meals and snacks	Sedentary
Nap or rest in bed	Sedentary
<b>Domestic and Leisure Activities</b>	
Sitting quietly (reading, television, playing cards)	Sedentary
Writing, using PC, typing	Sedentary
Standing quietly (for example waiting for something)	Light
Cooking, washing dishes	Light
Housekeeping and cleaning, washing and hanging out clothes	Moderate
Ironing, sewing	Light
Taking care of children calmly	Light
Taking care of babies or toddlers	Moderate
<b>Leisure Time Activities</b>	
Handy work standing up, auto mechanic, painting, wood work	Moderate
Gardening, racking leaves, pulling weeds, mowing the lawn...	Moderate

Working with a pitchfork	Vigorous
Spitting logs with an ax	Vigorous
Stacking fire place wood	Moderate
Singing	Light
Ballroom dancing	Moderate
Playing music (piano, violin, ...)	Light
Fishing	Light
<b>Getting to work or elsewhere</b>	
Walking normally	Moderate
Walking quickly or uphill	Moderate
Walking while carrying or pulling loads (cart on wheels, bags...)	Vigorous
Climbing up stairs	Not coded
Driving a car or a motorcycle	Light
Bicycling slowly (about 9 km/h)	Moderate
Bicycling fast (about 15 km/h)	Vigorous
<b>Sports</b>	
Bicycling (should not repeat questions 49-50)	Vigorous
Athletic walking	Vigorous
Running	Vigorous
Soccer	Vigorous
Basket-ball	Vigorous
Gymnastics	Moderate
Weight lifting	Moderate
Dancing (ballet, aerobics, rock)	Moderate
Swimming	Vigorous
Diving	Moderate
Skiing downhill, water skiing	Moderate
Cross-country skiing	Vigorous
Tennis (single), badminton	Vigorous
Tennis doubles	Vigorous
Squash	Vigorous
Golf, pulling a cart	Moderate
Golf (without pulling a cart)	Moderate
Judo, karate	Vigorous
Ice or roller skating	Vigorous

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**Additional file 2:** Example of calculation of the standardized times spent in each type of activity

A participant reports sleeping an average of 10 hours (600 minutes) per day. He also reports SB activities of 600 minutes/day, LPA activities of 200 minutes/day, MPA activities of 90 minutes per day and VPA activities of 10 minutes/day.

Calculation of non-sleep time (1 day =  $24 \times 60 = 1440$  minutes)

$$NST = 1440 - 600 = 840 \text{ minutes per day}$$

Calculation of total time spent in SB, LPA, MPA and VPA

$$T = 600 + 200 + 90 + 10 = 900 \text{ minutes/day} \quad \text{here, } T > NST$$

Calculation of the percentage of time spent in each type of activity

$$\begin{aligned} P_{SB} &= 600/900 &= 0.667 \text{ or } 66.7\% \\ P_{LPA} &= 200/900 &= 0.222 \text{ or } 22.2\% \\ P_{MPA} &= 90/900 &= 0.100 \text{ or } 10.0\% \\ P_{VPA} &= 10/900 &= 0.011 \text{ or } 1.1\% \end{aligned}$$

The standardized times are thus

$$\begin{aligned} ST_{SB} &= 840 \times 0.667 \cong 561 \text{ minutes/day} \\ ST_{LPA} &= 840 \times 0.222 = 186 \text{ minutes/day} \\ ST_{MPA} &= 840 \times 0.100 = 84 \text{ minutes/day} \\ ST_{VPA} &= 840 \times 0.011 = 9 \text{ minutes/day} \end{aligned}$$

The calculation are similar if  $T < NST$