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Brief Report

Reference Values for Daily Physical Activity Measured with Accelerometers in a Danish Background Population between 18 and 80 Years of Age

Christine Krogsgaard Schrøder [1,2], Lisa Urup Tønning [1,2], Marianne Tjur [1], Pia Kjær Kristensen [1,2] and Inger Mechlenburg [1,2,*]

[1] Department of Orthopaedic Surgery, Aarhus University Hospital, Palle Juul-Jensens Boulevard 99, DK-8200 Aarhus, Denmark
[2] Department of Clinical Medicine, Aarhus University, Palle Juul-Jensens Boulevard 82, DK-8200 Aarhus, Denmark
* Correspondence: inger.mechlenburg@clin.au.dk; Tel.: +45-21-679-062

Abstract: Physical activity provides essential information to assess general health and evaluate the outcome of interventions. However, evaluation of physical activity necessitates reference values for comparison. The current study aimed to present reference values for accelerometer-based data on physical activity in a background population. We conducted a population-based cross-sectional study using accelerometer-based data on physical activity and self-reported data on demographics and health from a cohort of randomly selected individuals of 18–80 years of age registered in the Danish Civil Registration System (CRS) (n = 242). Participants took an average of 6095 daily steps, had an average cadence of 98.5, spent 3.7 h standing, 1.4 h walking, 3.8 min cycling, 7.0 h in sedentary activities, and had 43 sit to stand transfers. The results varied when examining sex and individual age groups. Our findings are important to clinical practice and research, as they provide sex- and age-specific reference values to enable comparison of daily physical activity levels.

Keywords: accelerometer-based data; reference data; physical activity; sedentary behavior

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1. Introduction

Physical activity provides essential information on functional capacity and is an important determinant of general health [1]. Moderate levels of daily physical activity, including walking and cycling, are known to lower the risk of, e.g., heart disease, cancer, chronic respiratory disease, and diabetes [2–5]. Monitoring physical activity can be used to assess the overall well-being of certain populations and to evaluate the outcome of clinical interventions. Monitoring physical activity includes four dimensions: frequency, intensity, time, and type (FITT) [6].

Assessment of physical activity is often achieved by self-reported questionnaires, which are easy and inexpensive [7,8]. However, questionnaires on daily physical activity may be difficult to complete, and participants tend to exaggerate the extent of physical activity and under-report time spent on sedentary activities [9–11]. The use of objective evaluation tools, such as accelerometer-based algorithms to measure physical activity, have thus expanded and improved the validity of data on sedentary behavior and daily physical activities such as standing, walking, and cycling [12–18]. Since accelerometers are wireless and simple to use for participants, they can be applied in research as well as in clinical practice in the future. However, the use of accelerometer-based data to evaluate physical activity necessitates reference values from the background population for comparison. Although monitoring of physical activity can be used to evaluate the outcome of interventions, existing reference values for objectively measured physical activity are limited, have focused on intensity or energy expenditure, and do not provide information on the type of physical activity [19–22].

This study aimed to present reference values for accelerometer-based data on physical activity in a background population using the FITT model, including number of steps, cadence, intensity, time spent sedentary, standing, walking, or cycling, as well as number of transfers from sitting to standing.

2. Materials and Methods

We conducted a population-based cross-sectional study using accelerometer-based data on physical activity and self-reported data on demographics and health from a cohort of randomly selected individuals using the Danish Civil Registration (CRS) System [23]. The study was approved by the Danish Data Protection Agency (journal number: 2013-41-1901).

2.1. Study Population

We identified a group of randomly selected residents from one of five Danish Regions, the Central Denmark Region (1,300,000 inhabitants), ≥18 years old and registered in the CRS System. Written invitations were sent from Aarhus University Hospital in eight rounds from April 2014 to April 2016. The invitation clearly stated that everyone invited was eligible to participate, regardless of their general health and physical fitness, if they were capable of walking around at home. A pre-paid return envelope and a consent form were enclosed with the invitation and those invited and accepting to participate could reply by mail, phone, or email.

2.2. Accelerometer-Based Data Collection

No later than two months after inclusion, a tri-axial accelerometer-based sensor (Ax3, Axivity, Newcastle upon Tyne, England), a log book, and a questionnaire containing demographic and health-related questions identical to a Danish National Health survey were sent to the participants [24]. Furthermore, hypo-allergenic double-sided tape (3 M, Maplewood, MN, USA) for mounting of the sensor, written instructions, illustrations on how to tape the sensor to the leg, and a pre-paid envelope for return of the accelerometer-based sensors to the hospital were forwarded. The participants were instructed to wear the sensor for 7 days to collect data on both weekdays and weekends while their habitual physical activity profile was measured by the accelerometer-based sensor. The sensor was mounted at the right mid-thigh between the major trochanter and lateral femoral condyle, with the y-axis of the sensor along the axis of the femur [13]. The sensor had to be removed during nighttime, during sleeping for more than one hour, and during both showering and swimming. Participants were instructed to note in a logbook if and for how long the accelerometer had been removed during the day. Sleeping time was detected as non-wear time and these data were excluded. Data from −8 g to 8 g were collected at 50 Hz and stored on a built-in memory chip with a capacity of 2 GB.

2.3. Accelerometer-Based Data Analysis

When the accelerometer-based sensor and participant logbook were returned to the hospital, a research assistant (M.T.) transferred the accelerometer data to a computer and processed the data using a validated algorithm [13]. Using a MatLab script specifically designed for this purpose, data were visually divided into days. All data were calibrated manually by selecting a period of walking in the dataset for each day to adapt variations in participants' height, morphology, sensor placement, walking style, and speed [12]. After calibration, data were run through the algorithm based on a decision tree and divided into time spent sedentary, standing, walking, and cycling (based on the average magnitudes of the three acceleration vectors and the gait cycle frequency). Furthermore, number of steps, transfers from sitting to standing, and cadence during walking were classified. Based on this information, the algorithm constructed an intensity parameter where every 10 second data window was grouped into one of the four categories: (i) very low-intensity physical activity, e.g., sitting or standing (0–0.05 g); (ii) low-intensity physical activity, e.g., standing or shuffling (0.05–0.1 g); (iii) moderate-intensity physical activity, e.g., slow or normal walking (0.1–0.2 g); and (iv) high-intensity physical activity, e.g., fast walking, running, or jumping (>0.02 g) [12].

2.4. Participant Characteristics

From the questionnaire, the following participant characteristics were included: age (18–29 years, 30–29 years, 40–49 years, 50–50 years, 50–69 years, and ≥70 years); sex; height (m); weight (kg); body mass index (BMI) (kg/m^2); marital status (married, cohabiting, and single); education (primary school (grade 0–10) or secondary school (more than primary school, but no university degree) and higher education (obtained university degree)); back pain (yes/no); and headache (yes/no).

2.5. Statistical Analysis

Normality was assessed using QQ-plots and histograms. We tabulated the prevalence proportion and mean values with standard deviations (SD) of different participant characteristics according to age groups. We then calculated estimates on overall physical activity and according to age and sex groups and presented them with mean values and standard deviations (SD). Data were analyzed using STATA 17.0 (StataCorp, College Station, TX, USA).

3. Results

3.1. Participants

In total, 1569 people were invited to participate in the study and 361 accepted. We excluded participants where the accelerometers were either lost, not returned, or no valid data were collected from the accelerometer (n = 78). Furthermore, we excluded outliers that could have a disproportionate effect on statistical results, such as participants with less than 3 days of measuring time (n = 25), participants with a total measuring time of less than 24 h (n = 14), and participants with missing information on age (n = 2). Our final study cohort included 242 participants for analysis (Figure 1).

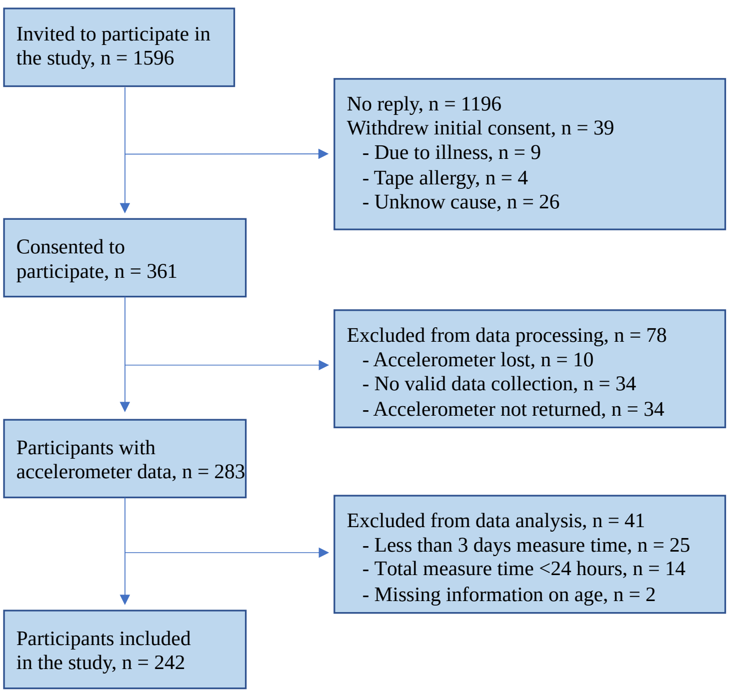

Figure 1. Flow chart on inclusion of participants.

3.2. Demographic and Health-Related Characteristics

Overall, the highest number of participants was in the age group 50–59 years and comprised slightly more females than males. Compared to the younger age groups, the older age groups were predominantly male, had a slightly higher self-reported BMI, were more often married, and were less likely to have a higher education. Furthermore, the older age groups more often reported having back pain but less often reported having headaches (Table 1).

Table 1. Population Characteristics According to Age Groups.

	Total	18–29	30–39	40–49	50–59	60–69	≥70
Number, n (%)	242 (100)	25 (10.3)	20 (8.3)	42 (17.4)	59 (24.4)	45 (18.6)	51 (21.1)
Male, n (%)	118 (48.8)	5 (20.0)	10 (50.0)	19 (45.2)	25 (42.4)	28 (62.2)	31 (60.8)
Height, mean (SD) [a]	173.3 (8.8)	171.3 (8.5)	174.1 (8.0)	175.5 (10.4)	175.1 (7.6)	173.4 (9.0)	170.1 (8.3)
Weight, mean (SD) [b]	77.6 (15.9)	66.4 (12.6)	78.5 (16.1)	77.6 (14.5)	78.9 (14.2)	82.8 (19.9)	76.7 (14.1)
BMI, mean (SD) [b]	25.8 (4.6)	22.5 (3.0)	25.9 (5.0)	25.0 (3.4)	25.7 (4.7)	27.4 (5.7)	26.4 (4.1)
Marital status, n (%) [a]	158 (65.3)	7 (28.0)	13 (65.0)	34 (81.0)	38 (64.4)	37 (82.2)	29 (58.0)
Married	31 (12.8)	7 (28.0)	*	5 (11.9)	8 (13.6)	4 (8.9)	*
Cohabiting	52 (21.49)	11 (44.0)	*	3 (7.1)	13 (22.0)	4 (8.9)	*
Single	158 (65.3)	7 (28.0)	13 (65.0)	34 (81.0)	38 (64.4)	37 (82.2)	29 (58.0)
Education, n (%) [d]							
Primary or secondary	131 (54.1)	15 (60.0)	8 (40.0)	18 (42.9)	31 (52.5)	27 (60.0)	32 (62.8)
Higher	107 (44.2)	9 (36.0)	12 (60.0)	24 (57.1)	27 (45.8)	18 (40.0)	17 (33.3)
Back pain [c]							
Yes	110 (45.5)	10 (40.0)	9 (45.0)	15 (35.7)	27 (45.8)	24 (53.3)	25 (49.0)
No	129 (53.3)	15 (60.0)	11 (55.0)	27 (64.3)	32 (54.2)	21 (46.7)	23 (45.1)
Headache							
Yes	59 (24.4)	8 (32.0)	7 (35.0)	12 (28.6)	12 (20.3)	13 (28.9)	7 (13.7)
No	177 (73.1)[c]	17 (68–0)	13 (65.0)	30 (71.4)	46 (76.0)	31 (71.1)	39 (76.5)

* Number not reported due to issues with anonymity caused by fewer than 3 participants; [a] one missing, [b] two missing, [c] three missing, [d] four missing, primary or secondary education: primary school (grade 0–10) or secondary school (more than primary school, but no university degree); higher education: obtained university degree; SD, standard deviation, BMI, body mass index.

3.3. Daily Physical Activity

The 242 included participants wore the accelerometer-based sensor for an average of 5.5 days, ranging from 3 to 10 days with an average of 12.2 h per day (Table 2). The 117 men wore the sensor for 5.7 days (range 3–10 days) with an average of 12.4 h per day, while the women wore the accelerometer for 5.3 days (range 3–8 days) with an average of 11.9 h per day (Table 3).

Table 2. Daily Physical Activity According to Age Group.

Dimension	**Total**	**18–29**	**30–39**	**40–49**	**50–59**	**60–69**	**≥70**
Parameter	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Frequency							
Steps, n	6095 (3351)	6563 (3894)	5688 (3827)	6028 (3612)	6086 (3785)	6874 (2954)	5406 (2254)
Intensity							
Cadence, steps/min	98.5 (9.0)	99.6 (6.4)	103.4 (7.8)	100.4 (5.5)	98.9 (10.8)	97.9 (9.5)	94.8 (8.9)
Very low intensity, %	75.6 (13.3)	69.7 (16.8)	75.8 (13.2)	73.2 (13.7)	74.3 (14.4)	74.7 (11.4)	82.5 (8.7)
Low intensity, %	13.0 (6.8)	15.9 (8.8)	12.7 (6.4)	13.8 (7.4)	13.6 (6.7)	13.2 (5.7)	10.1 (5.4)
Moderate intensity, %	6.8 (4.3)	8.2 (5.7)	6.4 (4.3)	7.4 (4.3)	7.1 (5.1)	7.1 (3.6)	5.0 (2.6)
High intensity, %	4.7 (3.3)	6.1 (3.2)	5.0 (3.3)	5.6 (3.1)	4.9 (3.7)	5.0 (3.2)	2.4 (1.7)
Time							
Wear time, h	12.2 (3.7)	11.3 (4.2)	10.4 (3.5)	10.3 (3.8)	11.3 (3.6)	12.9 (3.0)	15.0 (1.8)
Standing, h	3.7 (1.8)	3.3 (1.9)	3.6 (1.7)	3.3 (1.6)	3.7 (2.2)	3.9 (1.9)	4.0 (1.6)
Walking, h	1.4 (0.8)	1.5 (0.9)	1.3 (0.9)	1.4 (0.9)	1.4 (0.9)	1.6 (0.7)	1.3 (0.5)
Cycling, h	3.8 (9.0)	8.0 (12.6)	1.5 (3.2)	3.3 (11.6)	2.7 (6.1)	3.7 (7.6)	4.4 (9.5)
Sedentary, min	7.0 (3.1)	6.2 (3.0)	5.5 (2.8)	5.6 (2.7)	6.1 (3.0)	7.3 (2.7)	9.7 (2.4)
Type							
Sit to stand transfers, n	43 (27)	42 (21)	43 (28)	38 (15)	44 (32)	43 (18)	47 (38)
Cycle rotations, n	183 (480)	415 (759)	83 (201)	175 (649)	127 (282)	149 (298)	208 (517)

Data are presented according to the FITT model (frequency, intensity, time, and type); women; SD, standard deviation.

The participants took an average of 6095 (SD 3351) steps daily, and when examining individual age groups the oldest group had the lowest average daily number of steps (Table 2). Women had a higher number of average daily steps compared to men, however, this differed when examining the number of steps for the individual age groups (Table 3).

The overall population had an average cadence of 98.5 (SD 9.0), and the oldest age group had the lowest average cadence (Table 2). Furthermore, women had a higher average cadence compared to men, which was seen for all age groups except the two youngest groups (Table 3). When looking at the four intensity groups, there was a high proportion of participants in the very low-intensity activity group (75.6%) and a low proportion of participants in the high-intensity activity group (4.7%). The oldest age group represented the highest proportion of participants in the very low-intensity activity group and the lowest proportion of participants in the high-intensity activity group (Table 2). Furthermore, there were more women in the very low-intensity group but a slightly higher proportion of men in the low-, moderate-, and high-intensity groups. This was also seen when examining the individual age groups, except for the highest age group (Table 3).

The participants overall spent 3.7 h (SD 1.8) standing, 1.4 h (SD 0.8) walking, 3.8 min (9.0) cycling, 7.0 h (SD 3.1) in sedentary activities, and had 43 (SD 27) sit to stand transfers. The oldest age group had the highest daily average sedentary time, and the youngest age group had a higher average cycling time compared to the rest of the age groups (Table 2). Men and women had the same average daily walking time, standing time, and number of sit to stand transfers. For the individual age groups, walking time and number of sit to stand transfers differed slightly between men and women. Women had a higher average standing time than men in the higher age groups, but a lower average standing time than men in the lower age groups. Furthermore, men had a higher average daily cycling time compared to women overall and the majority of the individual age groups. Moreover, men had a higher average sedentary time compared to women (7.2 h, SD 3.2 vs. 6.7 h, SD 3.1), which also differed when examining the individual age groups (Table 3).

Table 3. Daily Physical Activity According to Age Groups and Stratified by Sex.

Dimension		**Total**	**18–29**	**30–39**	**40–49**	**50–59**	**60–69**	**≥70**
Parameter		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Frequency								
Steps, n	M	5911 (3192)	4354 (2055)	6497 (4166)	6723 (3562)	5199 (3238)	7198 (3383)	4886 (1919)
	W	6271 (3500)	7115 (4082)	4880 (3481)	5454 (3629)	6738 (4065)	6342 (2049)	6211 (2537)
Intensity								
Cadence, steps/min	M	96.1 (9.4)	99.6 (6.7)	104.2 (7.8)	98.3 (4.5)	96.4 (11.5)	95.7 (9.6)	91.7 (8.6)
	W	100.9 (7.9)	99.6 (6.5)	102.6 (8.2)	102.1 (5.8)	100.7 (10.1)	101.5 (8.4)	99.7 (6.9)
Very low intensity, %	M	74.1 (14.5)	66.7 (22.6)	74.5 (10.3)	66.0 (14.9)	73.2 (17.0)	71.3 (12.7)	83.4 (7.8)
	W	77.0 (12.1)	70.5 (15.7)	77.1 (16.1)	79.1 (9.2)	75.1 (12.5)	80.4 (5.5)	81.1 (9.9)
Low intensity, %	M	13.6 (7.2)	18.0 (13.4)	13.3 (5.0)	17.0 (8.2)	13.9 (7.4)	14.7 (6.3)	9.8 (5.2)
	W	12.4 (6.2)	15.4 (7.6)	12.2 (7.8)	11.2 (5.7)	13.4 (6.2)	10.8 (3.6)	10.6 (5.7)
Moderate intensity, %	M	7.1 (4.6)	8.5 (6.9)	6.8 (3.0)	9.4 (5.0)	7.2 (5.7)	8.0 (4.2)	4.6 (2.3)
	W	6.5 (4.1)	8.2 (5.6)	6.1 (5.4)	5.7 (2.6)	7.1 (4.6)	5.6 (1.7)	5.5 (3.0)
High intensity, %	M	5.2 (3.8)	6.8 (2.6)	5.4 (2.9)	7.6 (3.2)	5.6 (4.9)	6.0 (3.4)	2.2 (1.6)
	W	4.2 (2.7)	5.9 (3.4)	4.7 (3.8)	4.0 (1.8)	4.4 (2.5)	3.2 (2.0)	2.7 (1.9)
Time								
Wear time, h	M	12.4 (3.5)	11.4 (4.9)	11.4 (3.5)	10.7 (3.6)	10.4 (3.3)	12.9 (3.0)	15.4 (1.6)
	W	11.9 (3.8)	11.2 (4.1)	9.5 (3.5)	10.1 (4.0)	12.0 (3.8)	13.1 (3.1)	14.5 (2.0)
Standing, h	M	3.7 (1.8)	4.3 (3.2)	4.2 (1.3)	3.6 (1.6)	3.4 (2.2)	3.6 (1.8)	3.8 (1.5)
	W	3.7 (1.9)	3.1 (1.5)	2.9 (1.9)	3.0 (1.5)	4.0 (2.1)	4.5 (2.0)	4.2 (1.8)
Walking, h	M	1.4 (0.8)	1.1 (0.5)	1.5 (0.9)	1.6 (0.9)	1.2 (0.8)	1.7 (0.8)	1.2 (0.5)
	W	1.4 (0.8)	1.6 (1.0)	1.1 (0.8)	1.3 (0.9)	1.5 (0.9)	1.5 (0.5)	1.4 (0.6)
Cycling, h	M	4.8 (11.1)	14.2 (19.9)	2.6 (4.3)	4.8 (16.9)	1.7 (3.4)	4.4 (9.2)	6.8 (11.6)
	W	2.9 (6.3)	6.4 (10.2)	0.3 (0.7)	2.1 (3.7)	3.5 (7.5)	2.7 (3.9)	0.6 (1.4)
Sedentary, min	M	7.2 (3.2)	5.7 (2.3)	5.6 (2.7)	5.3 (2.5)	5.7 (2.8)	7.5 (2.8)	10.3 (2.2)
	W	6.7 (3.1)	6.4 (3.2)	5.4 (3.1)	5.8 (2.9)	6.4 (3.2)	7.1 (2.5)	8.9 (2.5)
Type								
Sit to stand transfers, n	M	43 (31)	42 (21)	47 (19)	36 (16)	38.4 (30.6)	40 (17)	51 (47)
	W	43 (24)	42 (22)	39 (35)	40 (14)	48.3 (32.4)	47 (21)	40 (14)
Cycle rotations, n	M	241 (622)	932 (1453)	151 (272)	263 (947)	93 (200)	175 (358)	322 (639)
	W	128 (279)	286 (443)	16 (37)	103 (199)	151 (331)	107 (156)	30 (70)

Data are presented according to the FITT model (frequency, intensity, time, and type); M men, W women, SD Standard Deviation.

4. Discussion

The purpose of this study was to present reference values for accelerometer-based data on physical activity from a background population. Among the 242 participants, there was an average of 6095 daily steps, the average cadence was 98.5, and 3.7 h were spent standing, 1.4 h walking, 3.8 min cycling, 7.0 h on sedentary activities, and average number of sit to stand transfers was 43. The results varied when examining sex and individual age groups.

Our study found that the oldest age groups had the lowest average number of daily steps, represented the highest proportion in the very low-intensity group, and had the lowest cadence and the most time spent sedentary compared to the younger age groups. This is in accordance with previous literature that shows that physical activity declines with age [25]. This may be caused by age-related reduction in muscle strength and changes in flexibility, agility, and endurance [26]. Furthermore, we found that men had the lowest cadence and average number of daily steps compared to women, which agrees with previous literature and is possibly due to women having a smaller step stride compared to men [19,27–29]. These age and sex differences are important to consider, e.g., when choosing physical interventions in an age- and sex-heterogenic group.

Previous studies utilizing accelerometers to assess physical activity have focused on specific patient groups and/or compared their physical activity to young and healthy subjects [14,15,17,18,30]. To our knowledge, no previous study has reported accelerometer-based daily physical activity following all the dimensions in the FITT model in a large background population. However, a previous study from the Netherlands by Senden et al. [19] reported accelerometer-based gait analysis according to sex and age for a group of healthy individuals. For all sex and age groups, the average cadence reported in the study by Senden et al. was higher than the average cadence reported in our study. This is possibly caused by the differences in study populations and in wear time, since the study by Senden et al. only included healthy individuals, whereas our study included individuals regardless of their general health and physical fitness, if they were capable of walking around at home. Furthermore, a Danish study by Johansson et al. [31] reported accelerometer-based daily physical activity for people residing in the capital of Denmark. Compared to our study, the study by Johansson et al. reported a much higher number of average daily steps despite reporting almost the same average daily time of walking, which indicates that capital residents tend to walk faster.

The strengths of our study include a valid objective accelerometer-based method used to collect data on daily physical activity [12,13]. Various methods have previously been utilized, many of them self-reported, using activity diaries or questionnaires, which entail a risk of recall bias where participants tend to exaggerate the level of physical activity and under-report time spent sedentary compared to data measured with an accelerometer [10,11]. However, we used a specific accelerometer (the Ax3, Axivity, Newcastle upon Tyne, UK), placed laterally on the thigh, and used a specific algorithm. It is possible that results obtained by another accelerometer, another positioning, or another algorithm could be different. Furthermore, it is a limitation in our study that the accelerometer-based method cannot differentiate between sitting and lying down, which entails that different types of sedentary behavior were not included. This implies that sleeping time was not automatically recorded and had to be assessed and excluded manually when participants forgot to remove their accelerometer. However, in those cases, it was quite evident in the data processing based on the time of day and lack of physical activity that these data should be excluded. Therefore, the risk of systematic misclassification of sleeping time and sedentary time is considered low. Furthermore, since our analysis of the accelerometer data, except for number of steps, was quite comprehensive and time-consuming, it may be difficult to apply to clinical practice. Lastly, the large number of non-replies during recruitment of participants may have reduced the external validity of our results.

5. Conclusions

This study provided reference values on physical activity from a Danish background population. The results of our study are important for clinical practice and research, as they provide sex- and age-specific reference values for comparison of daily physical activity.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: As part of the Data Use Agreement at the Danish Data Protection Agency, authors are not allowed to provide raw data. Upon reasonable request, the corresponding author will provide the statistical programming codes used to generate the results.

Conflicts of Interest: The authors declare no conflict of interest.

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