Accelerometry-based characteristics of overall sedentary behavior and sitting in middle-aged adults

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Abstract

The purpose of this study was to describe the accelerometry-based characteristics of overall sedentary behavior (SB) and sitting among adults under free-living conditions. Thirty-six (mean age 47.6 years) volunteers carried a waist-worn accelerometer for ≥ 4 days with data ≥ 600 min/d during 14 consecutive days. A machine learning (ML) based method was used to classify the patterns of SB and sitting from raw 3D acceleration. The participants spent most (69.3%) of their waking time in SB, and half (52.2%) of the SB was performed in a sitting posture. Men broke their overall sedentary time less often (4.1 vs. 6.1 bouts/h), but women sat more; however, women broke their sitting time as often as men (7.6 bouts/h). This study confirms that SB and sitting can be distinguished using ML methods, and more information about SB can be achieved when overall SB and sitting are analyzed separately in free-living conditions.

Keywords: sedentary behavior, sitting, accelerometer, raw data, machine learning

Introduction

Sedentary behavior (SB) is defined as any waking behavior performed in a sitting, reclining or lying posture with an energy expenditure ≤ 1.5 metabolic equivalents (METs) (Tremblay et al., 2017). Emerging evidence indicates that excessive time spent in SB is a risk factor for chronic disease morbidity and mortality regardless of the amount of physical activity (PA) (Fenton et al., 2017). In addition, long bouts of SB seem to increase the risk of the chronic diseases more than the total sedentary time (ST) (Healy et al., 2008) and different postures of SB seem to have different effects on health outcomes, e.g. more time spent in lying, but not sitting, is associated with decreased quality of life (Diniz et al., 2016). Nevertheless, there still exists lack of consensus on which patterns (e.g. number of bouts, mean bout duration) and postures (sitting, reclining, or lying) of SB have most negative impacts on health outcomes.

The development of monitor-based methods to measure SB has enabled researchers to gain more accurate information about total ST and the accumulation patterns of SB. Accelerometers are widely accepted as feasible monitors to measure SB, because they can be used for continuous assessment of both posture and energy expenditure in free-living conditions over multiple days without self-report bias (Fanchamps, van den Berg-Emons, Stam, & Bussmann, 2017; Janssen & Cliff, 2015; Sievänen & Kujala, 2017; Tremblay et al., 2017). However, the output of accelerometers is dependent on the attachment site and the used signal processing methods and thresholds (Fanchamps et al., 2017; Leinonen et al., 2017). For example, the posture-based thigh-worn ActivPal is more accurate in measuring ST than the count-based hip-worn Actigraph in highly sedentary occupational groups (Varela Mato, Yates, Stensel, Biddle, & Clemes, 2017). Although thigh can be considered the most accurate attachment site for the recognition of SB (Janssen & Cliff, 2015), a signal processing method for a reliable recognition of lying, sitting, and standing with a hip-worn accelerometer was recently presented (Vähä-Ypyä, Husu, Suni, Vasankari, & Sievänen, 2018). Because signal processing methods vary between the accelerometers, the results from studies employing different accelerometers' inbuilt proprietary units are not comparable (Leinonen et al., 2017). Clear description of the used accelerometer, attachment site, and data processing method has been proposed to improve the possibility to compare SB in different datasets and populations in the future studies (Wijndaele et al., 2015).

The association between SB and health outcomes seems to be dependent on the used definitions of sedentary bouts and breaks (Kim, Welk, Braun, & Kang, 2015). The Sedentary Behavior Research Network (SBRN) has recently presented a consensus of a terminology related to SB to assist researchers in investigating relationships among the different movement behaviors throughout the day. (Tremblay et al., 2017) In the standardized terminology a sedentary bout was defined as a period of uninterrupted ST and a sedentary break as a non-sedentary bout between two sedentary bouts. It is still unclear which is a minimum duration of the sedentary bout or the sedentary break, and whether the intensity of the break does matter for health (Janssen & Cliff, 2015; Tremblay et al., 2017).

SB profiles that describe different types or classes of SB and complex dependencies between SB, socioeconomic, environmental, behavioral, and health factors have become more popular in SB research (Evenson, Wen, Metzger, & Herring, 2015; Pyky et al., 2015). The SB profiles are often based on different clustering and grouping techniques which assign participants to one of several mutually exclusive classes that usually are not known in advance. These techniques combine information of multiple SB variables, which are derived from the raw data of an accelerometer, and categorize participants based on the associations between the variables (Evenson et al., 2015).

However, the consensus of the most relevant variables describing SB and sitting is still lacking. The methods which assess characteristics of free-living overall SB and sitting separately are needed to improve understanding of the health effects of different SBs. The aim of this study was to describe characteristics of accelerometry-based free-living overall SB and sitting separately in a sample of 47- to 49-years-old Finnish population using a machine learning based classification.

Material and methods

Participants

The 46-year data collection of the The Northern Finland Birth Cohort 1966 (NFBC66) (Rantakallio, 1988) was piloted in 2012 among 41 volunteers and the pilot data was used in this study. The methodology of the pilot study has recently been published elsewhere (Leinonen et al., 2017). In brief, 41 volunteers, who were born in 1964–65 and living in Oulu area or in neighboring municipalities, took part in baseline measurements and agreed to wear an accelerometer (Hookie AM20, Traxmeet Ltd, Espoo, Finland) for two weeks. Clinical examinations and questionnaires about health, lifestyle, socioeconomical, and occupational factors were performed and the accelerometers as well as the prepaid-postage padded envelopes for returning the monitors were given to the participants in the baseline visit. In the clinical examinations participants' height was measured to the nearest 0.1 cm using a stadiometer and body mass of the participants was measured to the nearest 0.1 kg using a digital scale. Body mass index (BMI) was calculated as weight divided by height squared (kg/m2).

All participants provided a written informed consent to take part in the study. The participants had the right to refuse to participate in or to withdraw from the study. The NFBC1966 study has been approved by the Ethics Committee of Northern Ostrobothnia Hospital District.

Monitor-based overall SB and sitting

Overall SB and sitting were measured in free-living conditions using Hookie AM20 accelerometer (6.6 × 2.7 × 1.3 cm, mass 15 g) attached with an elastic belt and worn on the right posterior side of the hip. Hookie AM20 measures triaxial accelerations in a range of ±16g and collects the raw acceleration signals at 100 Hz sampling frequency.

The manufacturer's default values for the thresholds of the power save mode were used. The accelerometer served as a data-logger only and did not provide feedback for the user. The participants were asked to wear the accelerometer for 14 days during the waking hours, except during showering, taking a sauna or other water-related activities.

The criterion for the analysis was the usage of the accelerometer at least 4 days, which included wear time at least 600 min per day (Husu et al., 2016). The patterns of overall SB and sitting were assessed separately from the raw 3D acceleration collected at 100 Hz sampling frequency using a custom made script (MATLAB R2016b, The MathWorks, Inc). The wear time was calculated by removing non-wear periods, defined as at least 30 min of consecutive zero values (Janssen & Cliff, 2015). In order to eliminate the noise from the wear time caused by dressing and undressing the accelerometer, one minute periods from the beginning and the end of the wear time were removed.

SB (sitting and lying) was recognized from the steady state wear time acceleration signals using a supervised machine learning (ML) model. Previously, higher accuracy in PA and SB classification has been suggested to be achieved using ML methods compared to the cut-point based methods (Ellis, Kerr, Godbole, Staudenmayer, & Lanckriet, 2016). The ML model used in this study was developed using MATLAB R2016b and has been described elsewhere (Tjurin et al., 2017). In brief, the model was trained and validated using the dataset of 22 working-age adults participating in nine controlled and supervised activities (lying on a sofa, sitting at a computer, standing/poster viewing, wiping and setting up kitchen table, floor cleaning, slow walking, fast walking, soccer, and jogging). The data used for model training were collected using the same accelerometer as in the present study. The activities were classified into five PA classes based on their movement patterns, posture, and intensity, which was measured using indirect calorimetry (COSMED K4 b2, Cosmed Ltd, Rome, Italy). The activities were classified as follows: lying (lying on a sofa), sitting (sitting at a computer), light PA (standing/poster viewing, table wiping, floor cleaning, and slow walking), moderate PA (fast walking), and vigorous PA (soccer and jogging). The ML model analyzed the data in 5 s epochs using the bagged trees classifier and in total 20 features (mean, minimum, maximum, zero crossing rate, and mean amplitude deviation (MAD), extracted in all three axes and the resultant acceleration). MAD indicates the mean difference between the mean value and the data points of the resultant acceleration in the same epoch (Vähä-Ypyä, Vasankari, Husu, Suni, & Sievänen, 2015). The epoch length 5 s was chosen, because short (< 10 s) epoch durations have been shown to record spontaneous intermittent PA and SB with sufficient accuracy (Fröberg, Berg, Larsson, Boldemann, & Raustorp, 2017; Matthews, Hagstromer, Pober, & Bowles, 2012). Features were selected using a sequential forward selection method in the prior study (Tjurin et al., 2017).

The performance of the model has been described and evaluated elsewhere (Tjurin et al., 2017). Using the leave-one-out cross-validation lying was recognized with 96.4 % sensitivity and 99.2 % specificity, and sitting was recognized with 92.2 % sensitivity and 99.2 % specificity. Daily wear time was limited to 20 h in order to eliminate error from two subjects, who may have worn the accelerometer during sleeping. The time over the maximum daily wear time (> 20 h) was removed from the lying time that was accumulated after midnight when the participants were most likely sleeping. Sitting bouts were analyzed separately or they were combined with lying bouts to form sedentary bouts. A minimum of 30 s was used to define overall sedentary and sitting bouts and breaks in ST.

Several sedentary pattern variables, which were found in the literature, were observed from the extracted overall sedentary and sitting bouts separately and determined for each individual per day (see Table 1). For overall SB and sitting, the observed variables were total time, median bout length, 50 % weighted median bout length, maximum bout length, number of bouts, fragmentation index (FI), and the fraction of total ST accumulated in bouts longer than median bout. For breaks in ST, the observed variables were median break length, and the number of breaks at least 1 min.

[Table 1 near here]

Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, USA). The data of the first day (i.e. the day when participants received the accelerometers) and the data of the final days containing ≤ 14 hours of wear time (i.e. postage days) were excluded from the analysis. The average and median values of the overall SB and sitting variables were calculated through the personal median values of the subjects. Histograms were formed for describing the number of and the total time in overall sedentary and sitting bouts per day of < 15 min, 15-29.99 min, 30-59.99 min, 60-119.99 min, and ≥ 120 min. Statistical differences between men and women were performed using an independent samples t-test (normal distribution) or a Mann-Whitney U-test (non-normal distribution). A p-value less than 0.05 was considered statistically significant.

Results

Thirty-six (87.8 %) of the participants had worn the accelerometer at least four valid days (≥ 600 min/d) (in total 465 days). Demographic characteristics of the participants included in the analyses are shown in Table 2.

[Table 2 near here]

The median number of valid days was 13 (interquartile range, IQR 1) and the median wear time of the accelerometer was 804.3 min/d (IQR 116.6). The subjects spent 69.3 % of their waking hours in overall SB (lying and sitting) (557.6 min/d), of which 290.8 min/d (52.2 %) was performed in a sitting posture.

Overall SB and sitting variables among men and women are presented in Table 3. Overall SB was accumulated from longer bouts in men and the median sedentary bout length per day was 1.3 min longer in men (5.6 vs. 4.3 min, $p < 0.05$). Similarly, the 50 % weighted sedentary bout per day was 13.1 min longer in men (39.5 vs. 26.4 min, $p < 0.05$). The FI of SB was 2.0 bouts/h (95% CI 0.5-3.6) greater in women (6.1 vs. 4.1 bouts/h, $p < 0.05$) and women had 16.6 (95% CI 5.9-27.3) sedentary bouts more than men per day (58.6 vs. 42.0 bouts/d, $p < 0.01$). In addition, the number of breaks in ST ≥ 1 min per day were higher in women than in men (47.1 vs. 33.5 breaks/d, $p < 0.01$). Daily ST (592.0 vs. 537.0 min/d) as well as the maximum sedentary bout length (90.0 vs. 78.8 min) and the fraction of the daily ST accumulated in bouts longer than median (91.0 vs. 90.0 %) were not significantly different between men and women. Compared with men, women had on an average 148.9 min (95% CI 72.0-225.8) more daily sitting (340.4 vs. 191.5 min/d, $p < 0.001$) and 18.4 (95% CI 7.9-28.9) sitting bouts more per day (44.1 vs. 25.7 bouts/d, $p < 0.01$), and women broke their sitting time as often as men (7.6 breaks/h).

[Table 3 near here]

The number of and the total time in a day spent in overall sedentary bouts (< 15 min, 15-29.99 min, 30-59.99 min, 60-119.99 min, and ≥120 min) among men and women are shown in Figure 1. Compared with men, women had higher frequency of less than 15 min sedentary bouts (47.6 vs. 31.1 bouts/d, $p < 0.01$) and 57.6 min/d greater total time in < 15 min sedentary bouts (195.2 vs. 137.7 min/d, $p < 0.01$). However, the significant differences between men and women were not found in the total times in 15-29.99 min, 30-59.99 min, 60-119.99 min, and ≥ 120 min sedentary bouts nor the number of 15-29.99 min, 30-59.99 min, 60-119.99 min, and ≥ 120 min sedentary bouts.

[Figure 1 near here]

Similarly, the number of and the total time per day spent in sitting bouts (< 15 min, 15-29.99 min, 30-59.99 min, 60-119.99 min, and ≥ 120 min) in men and women are shown in Figure 2. There were significant differences in the number of < 15 min (21.2 vs. 37.0 bouts/d, $p < 0.01$), 15-29.99 min (2.4 vs. 3.9 bouts/d, $p < 0.01$), 30-59.99 min (1.0 vs. 1.9 bouts/d, $p < 0.01$), and 60-119.99 min (0.2 vs. 0.5 bouts/d, $p < 0.05$) sitting bouts between men and women. Significant differences were also in the total times in < 15 min (90.7 vs. 149.8 min/d, $p < 0.01$), 15-29.99 min (48.9 vs. 82.4 min/d, $p < 0.01$), 30-59.99 min (40.4 vs. 72.9 min/d, $p < 0.05$), and 60-119.99 min (11.5 vs. 35.4 min/d, $p < 0.05$) sitting bouts between men and women. These results show that women had more number of and greater total time in < 15 min, 15-29.99 min, 30-59.99 min, and 60-119.99 min sitting bouts compared to men.

[Figure 2 near here]

Discussion and conclusion

For the first time, we described separately the characteristics of overall SB and sitting based on accelerometer measurements and machine learning classification among middle-aged adults under free-living conditions. This study showed that SB and sitting distinctions can be reliably made using ML based methods, and more information about SB can be achieved when overall SB and sitting are analyzed separately in free-living conditions. Moreover, for the sample studied, this method revealed that men spent their overall SB more often in prolonged bouts, but women sat more; however, women broke their sitting time as often as men.

The participants spent most of their waking wear time in SB, of which approximately half was sitting. The median lengths of the overall sedentary and sitting bouts were approximately 4 minutes indicating that the majority of the overall sedentary and sitting bouts were short. In addition, the overall ST seemed to accumulate in longer bouts than sitting time. Compared with men, women accumulated their ST more often in < 15 min bouts although the total ST was almost equal. Furthermore, the median sedentary bout was longer in men and men had on average fewer number of breaks per total ST than women. The similar associations were not found when sitting was analyzed separately. The total sitting time was greater in women, and compared to men, women had greater sitting time in bouts < 15 min, 15-29.99 min, 30-59.99 min, and 60-119.99 min.

Our results on the differences in overall SB between the genders are in line with the previous studies (Husu et al., 2016; van der Velde et al., 2017) in which men had more prolonged sedentary bouts than women. In another study (Sardinha, Magalhaes, Santos, & Judice, 2017) women seemed to have more breaks in ST per sedentary hour, but the difference between the genders was not statistically significant. However, the comparison of the results with previous studies is challenging, because definitions of the sedentary bouts and breaks vary between the studies and the patterns of the accelerometry-based free-living overall SB and sitting have not been analyzed separately in the previous studies. For instance, in the previous studies the break in ST was defined as a transition from sitting or lying to standing or stepping with a duration at least 1 min (van der Velde et al., 2017), a lying or sitting bout ending with a standing up (Husu et al., 2016), or at least 1 min interruption in ST with the count value greater than 100 counts per minute (Sardinha et al., 2017).

The strength of this study was that several variables of overall SB and sitting were analyzed separately from the raw 3D hip acceleration data using universal analysis methods. The developed ML based method can be used with any triaxial hip-worn accelerometer that collects raw acceleration data. However, the algorithm did not separate standing still, and the intensity during the breaks of SB was not investigated. Standing still for a long time has recently been associated with increased risks of cardiovascular diseases and musculoskeletal symptoms in the low back (Coenen et al., 2017). The intensity during the breaks in ST may also have an effect on health and for instance sedentary breaks containing light-intensity walking, but not standing, have shown to be beneficial for adults (Bailey & Locke, 2015). In this study, the accelerometer was not worn during the sleeping hours, which may also be considered as a limitation. Recently, it has been suggested to evaluate human’s PA and SB as a total accumulation patterns over the whole 24 hours per day (Sievänen & Kujala, 2017). Additionally, the study sample was relatively small including valid accelerometer data of 36 subjects within a narrow age range of middle-aged men and women.

In this study, we present a set of objectively assessed characteristics of overall SB and sitting measured with an accelerometer in free-living conditions using machine learning based classification. Further studies with larger populations are needed to characterize the association of ML-derived overall SB and sitting parameters with health issues.

Conflict of interest

The authors declare that they have no conflict of interest.

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Table 1. Overall sedentary behavior and sitting pattern variables used in the study

	Variable	Definition	References
Overall sedentary behavior and sitting	Total time (min/d)	Total sedentary/sitting time per day	Chastin & Granat, 2010; Chastin et al., 2015; Contardo Ayala et al., 2016; Fenton et al., 2017; Hartman et al., 2017; Husu et al., 2016; Kawagoshi et al., 2013; Lyden et al., 2012; Lyden et al., 2015; Sardinha et al., 2017; Tieges et al., 2015; van der Velde et al., 2017.
	Median bout length (min)	Median length of sedentary/sitting bouts per day	Tieges et al., 2015; Chastin et al., 2015.
	50% weighted median bout (min)	Length of sedentary/sitting bout that correspond to the half of the daily cumulatively accumulated sedentary/sitting time when bouts are ordered from shortest to longest	Tieges et al., 2015; Chastin & Granat, 2010; Chastin et al., 2015.
	Maximum bout length (min)	Maximum length of sedentary/sitting bouts per day	Kawagoshi et al., 2013.
	Number of bouts (bouts/d)	Number of sedentary/sitting bouts per day	Chastin et al., 2015; van der Velde et al., 2017; Husu et al., 2016; Kawagoshi et al., 2013; Lyden et al., 2012; Lyden et al., 2015.
	Fragmentation index (number of bouts/h)	Total number of breaks in sedentary/sitting time is divided by total hours spent in sedentary behavior/sitting per day	Chastin et al. 2015; Lyden et al., 2012; Lyden et al., 2015; Sardinha et al., 2017; Tieges et al., 2015.
	Fraction of the sedentary/sitting time accumulated in bouts > median bout (%)	Total time of sedentary behavior/sitting is divided by bouts longer than median by total sedentary/sitting time per day	Chastin & Granat 2010.
Breaks in sedentary time	Median break length (min)	Median length of sedentary breaks per day	Chastin et al., 2015.
	Number of breaks ≥ 1 min (breaks/d)	Number of at least 1 min sedentary breaks per day	Chastin et al., 2015; Fenton et al., 2017; Lyden et al., 2012; Sardinha et al., 2017; van der Velde et al., 2017.

Table 2. Demographic characteristics of the study participants

	Women (n = 24)	Men (n = 12)	All (n = 36)
Age (years)	47.5 (0.6)	47.8 (0.7)	47.6 (0.6)
Height (cm)	163.2 (6.9)	177.7 (5.8)	168.0 (9.5)
Body mass (kg)	72.6 (13.9)	80.1 (10.5)	75.1 (13.3)
BMI (kg/m2)	27.2 (4.8)	25.4 (3.0)	26.6 (4.3)

BMI = Body mass index. Values are mean (SD).

Table 3. Characteristics of overall sedentary behavior and sitting

	Variable	Women (n=24)	Men (n=12)	Total (n=36)	p-value	Reference range
Overall sedentary behavior (lying and sitting)	Total time (min/d) [1-2, 4-6, 8-12]	537.0 [146.9]	592.0 [125.7]	557.6 [143.3]	0.37_a	497.4-631.3 [1-2, 4-6, 8-12]
	Median bout length (min) [2, 11]	4.3 [1.5]	5.6 [2.7]	4.4 [2.1]	$< 0.05_a^*$	5.1-8.2 [2]
	50% weighted median bout (min) [1-2, 11]	26.4 [12.9]	39.5 [44.9]	28.9 [22.6]	$< 0.05_a^*$	17.3-102.6 [1-2]
	Maximum bout length (min) [7]	78.8 [50.1]	90.0 [110.0]	82.2 [57.0]	0.09_a	-
	Number of bouts (bouts/d) [2, 6-9, 12]	58.6 (15.2)	42.0 (14.2)	53.0 (16.7)	$< 0.01_b^*$	26.6-84.3 [2, 8]
	Fragmentation index (number of bouts/h) [2, 8-11]	6.1 (2.3)	4.1 (1.8)	5.4 (2.3)	$< 0.05_b^*$	2.21-10.7 [2, 8-10]
	Fraction of the daily sedentary time accumulated in bouts > median bout (%) [1]	90.0 [2.5]	91.0 [3.2]	90.7 [2.8]	0.30_a	71.5-95.4 [1]
Sitting	Total time (min/d) [3, 7]	340.4 (112.7)	191.5 (93.9)	290.8 (127.2)	$< 0.001_b^*$	316.0 [7]
	Median bout length (min)	3.7 [1.6]	3.9 [2.1]	3.8 [1.7]	0.62_a	-
	50% weighted median bout (min)	17.3 [9.4]	18.8 [13.8]	17.4 [9.9]	0.92_a	-
	Maximum bout length (min) [7]	58.1 [24.7]	44.0 [27.2]	49.4 [25.0]	0.27_a	40.0 [7]
	Number of bouts (bouts/d)	44.1 (15.6)	25.7 (12.2)	37.9 (16.8)	$< 0.01_b^*$	-
	Fragmentation index (number of bouts/h)	7.6 (2.5)	7.6 (2.4)	7.6 (2.5)	0.81_b	-
	Fraction of the daily sitting time accumulated in bouts > median bout (%)	88.6 [2.0]	88.0 [3.5]	88.4 [2.2]	0.55_a	-
Breaks in sedentary time	Median break length (min) [4, 8]	2.4 [0.5]	2.5 [0.4]	2.4 [0.4]	0.64_a	-
	Number of breaks ≥ 1 min (breaks/d) [2, 4, 8, 10, 12]	47.1 (14.0)	33.5 (12.4)	42.6 (14.8)	$< 0.01_b^*$	26.6-79.6 [2, 4]

References: [1] Chastin & Granat, 2010; [2] Chastin et al., 2015; [3] Contardo Ayala et al., 2016; [4] Fenton et al., 2017; [5] Hartman et al., 2017; [6] Husu et al., 2016; [7] Kawagoshi et al., 2013; [8] Lyden et al., 2012; [9] Lyden et al., 2015; [10] Sardinha et al., 2017; [11] Tieges et al., 2015; [12] van der Velde et al., 2017. Values are mean (SD) or median [IQR]. * A significant difference between men and women with $p < 0.05$. $_a$ = Mann-Whitney U-test, $_b$ = Independent-Samples T-test.

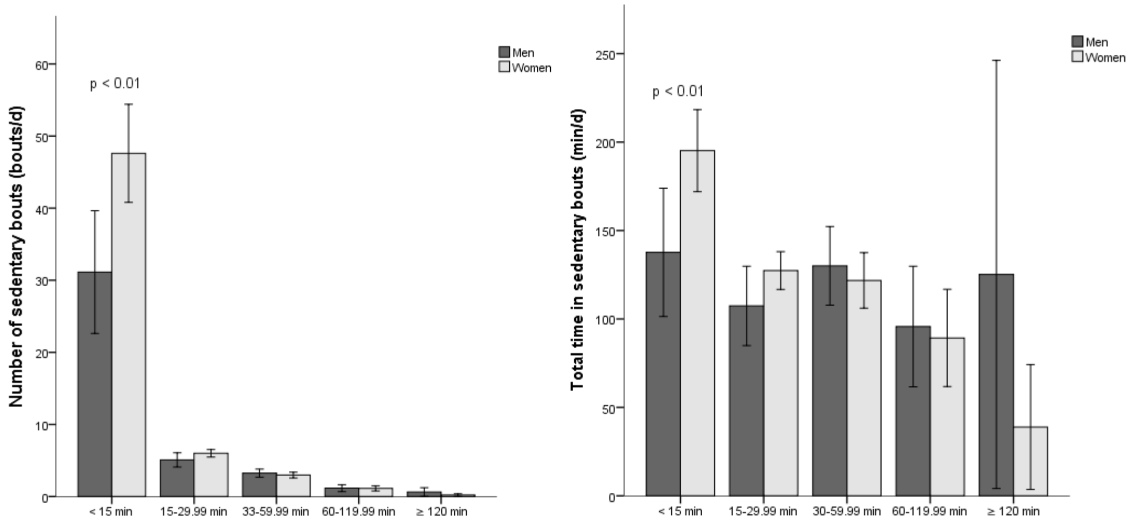

Figure 1. The number of different length overall sedentary bouts (left) and the total time in different length overall sedentary bouts per day (right) among men and women. Data shown as means and error bars represent 95% confidence intervals. P-values indicate significant differences between men and women.

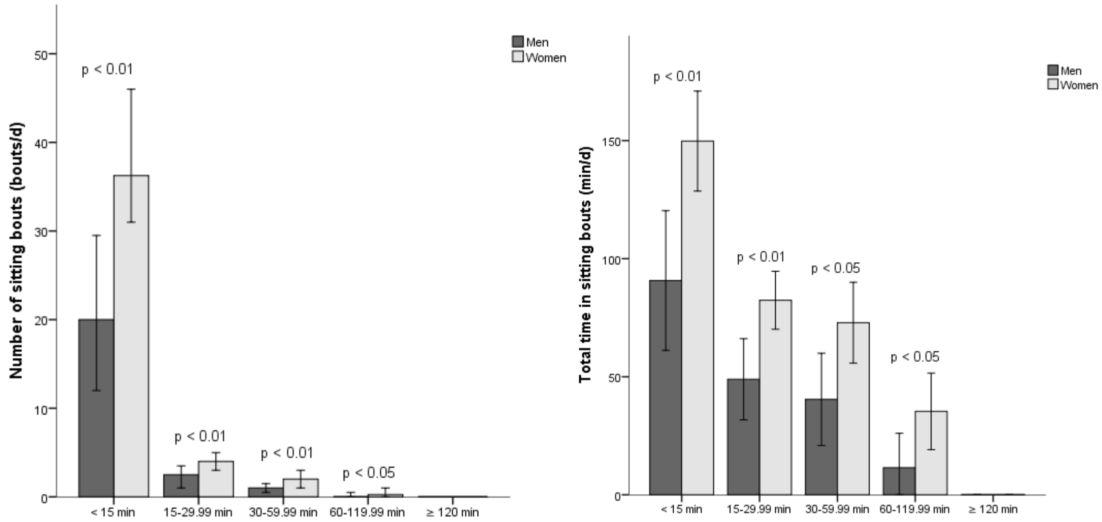

Figure 2. The number of different length sitting bouts (left) and total time in different length sitting bouts per day (right) among men and women. Data shown as means and error bars represent 95% confidence intervals. P-values indicate significant differences between men and women.