Sedentary behavior: Different types of operationalization influence outcome measures

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ABSTRACT

Introduction: Sedentary behavior (SB) influences health status independently of physical activity. The formal definition of SB is: "any waking behavior characterized by an energy expenditure ≤1.5 METs while in a sitting or reclining posture". However, measuring SB mostly does not include both the intensity and postural component. The aim of this study was to quantify the effect of type of operationalization of SB on total sedentary time and the pattern of SB.

Methods: 53 healthy subjects were measured 24h with a multi-sensor activity monitor that provides a valid one-second detection of body postures and movements and a calculated intensity measure. The SB outcome measures were: total sedentary time; number of sedentary bouts; mean bout length; fragmentation; and W-index. All outcomes were calculated for three types of operationalization of SB: 1) waking time in lying and sitting posture and below the sedentary intensity threshold (<0.016g comparable with Actigraph <150 counts, COMBI); 2) waking time in lying and sitting posture (POST); 3) waking time below the sedentary intensity threshold (<0.016g, INT). Outcome measures based on these three operationalizations were compared with repeated measures ANOVA.

Results: Total sedentary time was significantly different ($p<.001$) between all three conditions: 505.8 (113.85) min (COMBI), 593.2 (112.09) min (POST), and 565.5 (108.54) min (INT). Significant differences were also found for other outcome measures.

Conclusion: Our study shows that type of operationalization significantly affects SB outcome measures. Therefore, if SB is defined according to the formal definition, measurements must include both the intensity and postural component.

INTRODUCTION

In the initial stages of promoting an active and healthy lifestyle, research and guidelines mainly focused on total amount of physical activity (PA)[1], such as total number of steps and amount of time of moderate-to-vigorous PA. However, over the last-decade research has shown that sedentary behavior (SB) is also a determinant of health independent of the amount of PA[2,3]. As a result, lifestyle interventions should not only aim at optimizing PA, but also at reducing SB.

For clarity, a consistent definition of SB is proposed: any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents (METs) and a sitting or reclining posture[4]. This definition indicates that two behavioral components are crucial: an intensity/energy expenditure component and a postural component. However, in SB research typically only one of these components is assessed. For example, in many studies total sedentary time and sedentary bouts are calculated from objectively measured epochs characterized by movement counts below a specified threshold, where that threshold is generally assumed to represent 1.5 METs[5,6]. This intensity approach has its origin in a huge amount of available devices that measures acceleration and convert this into counts as their output, representing the intensity of the movement. On the other hand, some studies mainly focus on the postural component of the SB definition, e.g., by assessing the amount of sitting/reclining[7,8]. Thus, so far SB has rarely been measured objectively according to its formal two-component definition.

SB research is thus characterized by a variety in operationalization of SB, and in methods how SB is measured. This variety hinders progress, because results of studies may depend on the way SB is operationalized[7,9]. Consequently, results cannot be compared between studies, and the process of obtaining insight in the working mechanisms of SB is hindered. In addition, SB outcome measures should not only include the total amount of SB, but also data on bouts of SB, as there is some evidence that not only is the amount of SB important, but also the pattern by which sedentary time is accumulated[5,10]. So far, the effect of different types of operationalization of SB on SB outcome measures has not been quantified. A currently available data set containing objectively measured data of both the intensity and postural component, allows quantification of this effect. The aim of this study was therefore to quantify the effect of the type of operationalization of SB on SB outcome measures. SB was studied using only the intensity data, only the postural data, and data of both components.

METHODS

Study sample

Data was used from previous studies in which healthy people were control subjects for patients with chronic conditions[11-14]. Besides matching for age and gender there were no specific inclusion or exclusion criteria for these healthy control subjects. We used no other selection criteria for using the existing data, except that raw data had to be available. For this explorative study, no sample size calculation was performed, all available data was used. We included data from 53 healthy subjects, 19 male and 32 female; information of gender was missing for 2 subjects. The subjects had a mean (SD) age of 48.4 (14.6) years. All subjects gave their informed consent and all studies were approved by the medical ethical committee of the Erasmus MC.

Measurements

SB was objectively measured with the Vitaport activity monitor (TEMEC, Kerkrade, The Netherlands) which is based on long-term measuring of signals from body-fixed accelerometers. The device is valid to quantify a set of body posture and movements (P&M, e.g., sitting, standing, and walking)[15-17], provides information on the duration of these activities, and is applied in various descriptive, evaluative, and comparative studies[18]. Besides the duration of P&M, information which is related to the intensity of the P&M can be obtained, and was shown to correlate well with oxygen uptake and heart rate[19]. The device consists of three body-fixed accelerometers, one attached to each thigh (uni-axial) and one to the trunk (sternum position, bi-axial). The accelerometers sampled with 128 Hz, and were connected to the data recording unit worn around the waist, which stored the data with 32 Hz. Subjects were instructed to continue their ordinary daily life and to wear the device continuously; however, bathing, showering, and swimming was not possible during the measurement period. The principles of the activity monitor were only explained after study completion to avoid measurement bias. The measurements had a minimum duration of one full-day (24h), and were conducted during consecutive weekdays.

Data processing

If Vitaport measurements consisted of several days, the first full-day was used for analysis. According to the definition of SB only data from waking hours was used. We determined the start and end of these waking hours by inspection of the raw signals and used the diaries filled out by the subjects during the measurement. In case of uncertainty, agreement with a second researcher was obtained.

The subsequent steps of the Vitaport for the activity detection and its post processing were described previously[20]. Briefly, the Vitaport automatically detects each second a P&M (lying, sitting, standing, walking, cycling, and general noncyclic movements). This detection is based on feature signals (the angular, motility, and frequency feature; all 1Hz) derived from each raw acceleration signal, activity-specific settings, and a minimal distance-based detection method. We used this standard output signal as postural component. For the intensity component we used the body motility output which is the average of the motility feature signal of each sensor. This motility depends on the variability around the mean of the raw acceleration signal, and is created by high pass filtering (0.3Hz), rectifying and averaging over 1 s, and is expressed in g (9.81m/s2). The body motility output is comparable with the output of devices which provide a movement intensity measure (counts); however, there is no threshold for SB for this body motility output known yet. Therefore, we performed some extra measurements in which we simultaneously used the Vitaport and Actigraph (GT3X, Actigraph, Pensacola, Florida, USA). This is a well-known tri-axis accelerometer with movement counts as output, and frequently used to measure SB. During those measurements 8 healthy subjects (2 men; mean age 31 years), performed various activities (sitting, standing and, walking) with different intensities. After these measurements, we related the Actigraph movement counts with the synchronous Vitaport body motility output. As expected, these were strongly related ($R=0.9$, $p<0.001$), and from that relationship we could determine a threshold for SB for the Vitaport body motility output. A threshold of 150 Actigraph movement counts[21] corresponded with a Vitaport body motility value of 0.016g. The body motility output was converted into a binary time series (0/1) with "1" expressing seconds that were below the threshold of 0.016g and thus classified as sedentary. Thereafter a duration threshold of 5 s was applied, to perform comparable post processing of the body motility than of the P&M detection incorporated in the analysis of Vitaport itself[20].

Outcome measures

SB outcome measures were calculated for the three types of operationalization of SB:

- Combined operationalization: waking time in lying and sitting posture with a low intensity (<0.016g, comparable with Actigraph <150 counts).
- Posture operationalization: waking time in lying and sitting posture.
- Intensity operationalization: waking time with a low intensity (<0.016g, comparable with Actigraph <150 counts).

For each operationalization we quantified SB by calculating several outcome measures using a custom-made Matlab program. In this program, new binary (0/1) time series were created for each operationalization of SB, with "1" expressing seconds that satisfied that operationalization. In this way SB bouts (periods of uninterrupted samples of SB) were created. Due to the "5 seconds rule" applied to the posture/movement detection by Vitaport and to the METs time series in our analysis, bouts and periods between bouts last at least 5 seconds.

Subsequently, for each of three binary SB time series the following SB outcome measures were calculated:

1. Total sedentary time (minutes): absolute total time of SB.
2. Number of sedentary bouts: number of uninterrupted periods of SB.
3. Mean bout length (seconds): since the length of the bouts was log normally distributed, the mean of the natural log of the data was calculated and back transformed into the original scale.
4. Fragmentation: number of bouts divided by total sedentary time[22]. A higher fragmentation indicates a more fragmented time spent sedentary. This means there are less prolonged uninterrupted bouts.
5. W-index: the fraction of the total time accumulated in bouts longer than the median bout length[23].

Statistical analysis

Statistical analysis was performed with SPSS software version 21. Repeated measures ANOVA with the different types of operationalization of SB as within subject variable were performed to assess the effect of operationalization on each of the SB outcome measures separately. Maulchy's test was used to test sphericity, and in cases of sphericity violations, Greenhouse-Geisser estimates were used for correcting the degrees of freedom of the F-tests. Significance levels were set at $p < .05$ and Bonferroni corrections were used to correct for multiple pairwise comparisons. Besides calculating results, they were also visualized in scatterplot.

RESULTS

Overall and in the post-hoc analysis a significant difference between the types of operationalization of SB for all outcome measures was found (Table 2.1 and 2.2). It can be seen that the amount of SB was lower when measured with the intensity operationalization (mean 565.5, SD 108.54 min) than with the posture operationalization (mean 593.2, SD 112.09 min). There was even less sedentary time when measured with the combined operationalization. This is also seen in the scatterplot were most values of posture vs intensity were below the line x=y and above that line in the other two comparisons (Figure 2.1). The results of the number of sedentary bouts and the fragmentation were similar: in both outcome measures the intensity operationalization was highest (number of bouts: mean 336.6, SD 110.75; fragmentation: mean 0.628, SD 0.2712) and the posture operationalization lowest (mean number of bouts 86.2, SD 31.72; mean fragmentation 0.152, SD 0.0727). The values in the scatterplots for these outcome measures containing the intensity operationalization were above the line x=y. The results of the mean bout length had a reversed pattern compared to the result of the number of sedentary bouts

Table 2.1 Results of the repeated measures ANOVA, focusing on the effect type of operationalization of SB on SB outcomes.

Outcome measure	Sphericity χ^2, df=2 *(p-value)*	Correction df with Greenhouse-Geisser	F-test, *(p-value)*
Total sedentary time (min)	31.86 *(0.000)*	ε=0.68	*F*(1.37, 71.01) = 78.3, *(0.000)*
Number of sedentary bouts	9.36 *(0.009)*	ε=0.86	*F*(1.71, 89.07) = 256.8, *(0.000)*
Mean bout length (sec)	37.99 *(0.000)*	ε=0.66	*F*(1.31, 68.19) = 125.4, *(0.000)*
Fragmentation	33.18 *(0.000)*	ε=0.68	*F*(1.35, 70.36) = 169.1, *(0.000)*
W-index	17.85 *(0.000)*	ε=0.77	*F*(1.54, 80.29) = 23.9, *(0.000)*

Table 2.2 Mean values (SD) of all outcome measures of the three operationalization of the chosen threshold.

Outcome measure	Threshold 0.016g	P value	%
Total sedentary time (min)		> 0.01	
Combined	505.8 (113.85)		100
Posture	593.2 (112.09)		117
Intensity	565.5 (108.54)		112
Number of bouts		> 0.001	
Combined	204.8 (99.84)		100
Posture	86.2 (31.72)		42
Intensity	336.6 (110.75)		164
Mean bout length (sec)		> 0.001	
Combined	72.2 (31.68)		100
Posture	148.6 (66.73)		206
Intensity	38.9 (10.37)		54
Fragmentation		> 0.001	
Combined	0.428 (0.2434)		100
Posture	0.152 (0.0727)		36
Intensity	0.628 (0.2712)		147
W-index		> 0.01	
Combined	0.912 (0.0268)		100
Posture	0.937 (0.0229)		103
Intensity	0.925 (0.0267)		101

P value is the largest p values of all three post-hoc combinations (combined vs posture; combined vs intensity; posture vs intensity). Total sedentary time: combined vs posture p> 0.001; combined vs intensity p> 0.001; posture vs intensity p> 0.01. W-index: combined vs posture p> 0.001; combined vs intensity p> 0.001; posture vs intensity p> 0.05.

and the fragmentation. The W-index results were similar to the result of total sedentary time, however in the scatterplots can be seen that there is more spread around the line x=y. In addition, not all scatterplots follow the line x=y: the scatterplots of the number

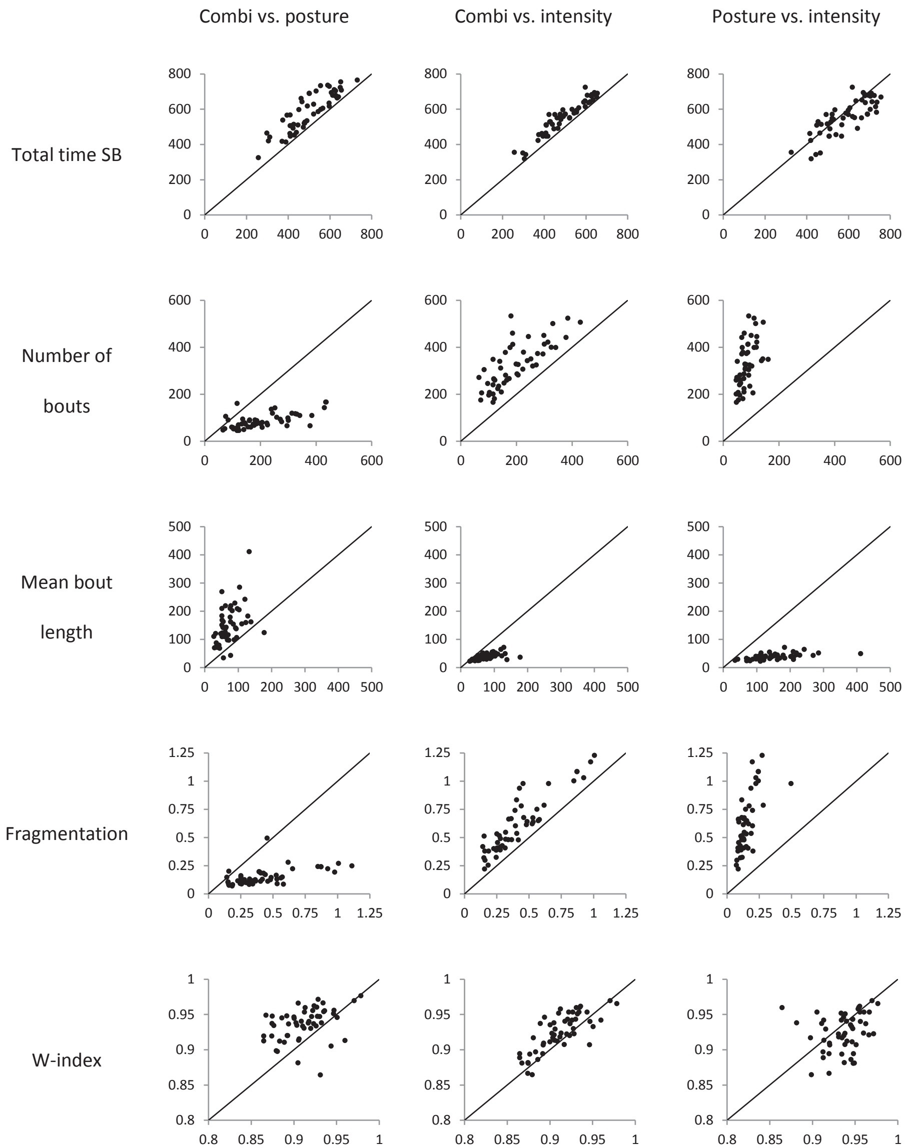

Figure 2.1 Scatterplots of all outcomes in which three operationalizations are visualized. First mentioned operationalization is on the x axes, second one on the y axes.

of bouts and fragmentation of 'posture vs intensity' is very steep, while the mean bout length and the W-index of 'combi vs posture' is more round.

DISCUSSION

The aim of this study was to quantify the effect of the type of operationalization of SB on SB outcome measures. We showed that the type of operationalization significantly affects the total sedentary time and the pattern how this time is accumulated. The results were not only statistically significant, but can also be considered relevant. For example, when considering the combined operationalization as 100% – which includes both the posture and intensity component in line with the definition – the total time of the postural operationalization is about 117% and that of the intensity operationalization 112%. However, in the distribution of this time, even much larger differences were found. The number of bouts of the postural operationalization is only 42% of the combined one and those of the intensity operationalization is about 164%. The opposite is true for the mean bout length, which was – relative to the combined operationalization – 206% in the posture operationalization and 54% in the intensity operationalization. These differences express the effect of operationalization on mean outcome measures, while the scatter plots also show a large variability. These results indicate that the type of operationalization cannot be neglected, and that it has to be considered when interpreting and comparing studies of SB research.

The effect of the type of operationalization on SB outcome measures varied, and most of these effects can be logically explained. For example, when comparing the combined operationalization with the postural operationalization, the total sedentary time will always be lower in the combined operationalization, because of the additional requirement (low intensity). In the combined operationalization, the number of sedentary bouts was higher: e.g., one bout in the postural operationalization may become two shorter bouts in the combined operationalization because of samples within that bout above the intensity threshold. When we compare the combined operationalization with the intensity operationalization there again is an additional requirement (lying or sitting), resulting in a lower total sedentary time in the combined operationalization. However, in contrast to the comparison between the combined and postural operationalization, there were less bouts in the combined operationalization when compared to the intensity operationalization. Like in the comparison of the combined and postural operationalization, intensity-based bouts of SB can be split up because of the extra (postural) requirement, which will result in more bouts in the combined operationalization. However, this effect is overruled by the effect of bouts that will be completely skipped by adding the postural requirement. Most likely this is the result of time spent standing (still). Previous research also stated that standing (still) was mostly classified as SB when using data based on movement intensity[7,9,24]. The added value of the current study, therefore, is not only to indicate that there is an effect of the operationalization of SB, but also to quantify this effect.

Accelerometers such as the Actigraph are commonly used for assessing SB, and their output in counts is comparable with our intensity operationalization. Although commonly used, this operationalization with count-based accelerometers has an important limitation. Contradictive results are found about the energy cost of standing: some studies found no difference with the energy cost of sitting, while others did find difference, although small[25-27]. Regular count-based accelerometers cannot reliably distinguish between sitting without significant movement and standing without significant movement. As a result, count-based accelerometers will probably mostly overestimate SB by measuring also some standing[6,24]. There is evidence that upper leg inclination data, which can detect body postures, have higher precision and accuracy in assessing sedentary time than accelerometers when compared to direct observation[6,9]. The most widely used example of this principle is the activPAL, which is comparable with the posture operationalization. Although this device is probably more precise in measuring sitting time, this does not mean it is more precise in measuring sedentary time. Sitting is not always sedentary; studies about energy expenditure have reported that some sitting activities exceed the sedentary threshold of 1.5 METs[27,28].

Based on the previous mentioned limitations of commonly used devices and the results of the current study, we recommend to measure both the intensity and postural component when the purpose is to quantify SB according to its formal definition; activities <1.5 METs in sitting of reclined position. It should be clear that it was not our purpose to assess the definition and the validity of its two-component character. Our study does not provide conclusions about which operationalization has, for example, the strongest relationship with health status. We are aware of the fact that the definition of SB is – so far – not strongly based on empirical studies, and that much is still uncertain about the working mechanisms of SB and about how SB contributes to health risks[29]. Therefore, it does not automatically mean that this combination of intensity and posture provides the most valid operationalization from the health perspective. Elucidating these working mechanisms will be one of the challenges of the future, and this increased knowledge will certainly affect the determination of the most reliable and valid operationalization of SB . However, based on the current definition of SB and the results of our study we suggest to measure simultaneously intensity and posture in SB research.

Some limitations of the study have to be mentioned. First of all, our intensity threshold of 0.016g was carefully determined by comparing with Actigraph, but not based on simultaneous measurement of energy expenditure. However, previous research has shown that the movement intensity time series correlated well with oxygen uptake and heart rate19. Furthermore, Boerema[30] performed a sensitivity analysis, which showed that sedentary pattern measures of daily living of office workers showed relatively low sensitivity to changes in the threshold for SB. Therefore, we think that the threshold used is reliable and small changes to a better threshold will not influence the results of our study. Another limitation is that the way we calculated intensity is different – too some extent – from other currently available accelerometers. In general, the way the body motility was calculated is quite similar to the way that movement intensity counts are calculated in other devices such as the Actigraph. However, our multi-sensor input is different from one-unit devices, and the algorithms are not exactly the same. This is a limitation, but at the same time all accelerometers have their device specific algorithms and settings, which means that comparing results of different studies always will be arbitrary[7,9].

CONCLUSION

It can be concluded that the type of operationalization of SB significantly affects SB outcome measures. To our knowledge, this is the first study quantifying this effect of operationalization. Based on these results, we recommend if measuring SB according to its formal definition of "any waking behavior characterized by an energy expenditure ≤1.5 METs and a sitting or reclining posture", measurements must include both the intensity and posture component.

REFERENCES

1. Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines Advisory Committee Report. *Washington, DC: US Department of Health and Human Services.* **2008**.
2. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Ann Intern Med.* **2015**;162:123-132.
3. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. *Diabetologia.* **2012**;55:2895-2905.
4. Sedentary Behaviour Research Network. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". *Appl Physiol Nutr Metab.* **2012**;37:540-542.
5. Carson V, Wong SL, Winkler E, Healy GN, Colley RC, et al. Patterns of sedentary time and cardio-metabolic risk among Canadian adults. *Prev Med.* **2014**;65:23-27.
6. Judice PB, Santos DA, Hamilton MT, Sardinha LB, Silva AM. Validity of GT3X and Actiheart to estimate sedentary time and breaks using ActivPAL as the reference in free-living conditions. *Gait Posture.* **2015**;41:917-922.
7. Janssen X, Basterfield L, Parkinson KN, Pearce MS, Reilly JK, et al. Objective measurement of sedentary behavior: impact of non-wear time rules on changes in sedentary time. *BMC Public Health.* **2015**;15:504.
8. van der Berg JD, Stehouwer CD, Bosma H, van der Velde JH, Willems PJ, et al. Associations of total amount and patterns of sedentary behaviour with type 2 diabetes and the metabolic syndrome: The Maastricht Study. *Diabetologia.* **2016**;59:709-718.
9. Kozey-Keadle S, Libertine A, Lyden K, Staudenmayer J, Freedson PS. Validation of wearable monitors for assessing sedentary behavior. *Med Sci Sports Exerc.* **2011**;43:1561-1567.
10. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, et al. Breaks in sedentary time: beneficial associations with metabolic risk. *Diabetes Care.* **2008**;31:661-666.
11. de Groot IB, Bussmann JB, Stam HJ, Verhaar JA. Actual everyday physical activity in patients with end-stage hip or knee osteoarthritis compared with healthy controls. *Osteoarthritis Cartilage.* **2008**;16:436-442.
12. Michielsen ME, Selles RW, Stam HJ, Ribbers GM, Bussmann JB. Quantifying nonuse in chronic stroke patients: a study into paretic, nonparetic, and bimanual upper-limb use in daily life. *Arch Phys Med Rehabil.* **2012**;93:1975-1981.
13. Schasfoort FC, Bussmann JB, Zandbergen AM, Stam HJ. Impact of upper limb complex regional pain syndrome type 1 on everyday life measured with a novel upper limb-activity monitor. *Pain.* **2003**;101:79-88.
14. van der Slot WM, Roebroeck ME, Landkroon AP, Terburg M, Berg-Emons RJ, et al. Everyday physical activity and community participation of adults with hemiplegic cerebral palsy. *Disabil Rehabil.* **2007**;29:179-189.
15. Bussmann HB, Reuvekamp PJ, Veltink PH, Martens WL, Stam HJ. Validity and reliability of measurements obtained with an "activity monitor" in people with and without a transtibial amputation. *Phys Ther.* **1998**;78:989-998.
16. Bussmann JB, Tulen JH, van Herel EC, Stam HJ. Quantification of physical activities by means of ambulatory accelerometry: a validation study. *Psychophysiology.* **1998**;35:488-496.
17. van den Berg-Emons HJ, Bussmann JB, Balk AH, Stam HJ. Validity of ambulatory accelerometry to quantify physical activity in heart failure. *Scand J Rehabil Med.* **2000**;32:187-192.

18. van den Berg-Emons RJ, Bussmann JB, Stam HJ. Accelerometry-based activity spectrum in persons with chronic physical conditions. *Arch Phys Med Rehabil*. **2010**;91:1856-1861.
19. Bussmann JB, Hartgerink I, van der Woude LH, Stam HJ. Measuring physical strain during ambulation with accelerometry. *Med Sci Sports Exerc*. **2000**;32:1462-1471.
20. Bussmann JB, Martens WL, Tulen JH, Schasfoort FC, van den Berg-Emons HJ, et al. Measuring daily behavior using ambulatory accelerometry: the Activity Monitor. *Behav Res Methods Instrum Comput*. **2001**;33:349-356.
21. Carr LJ, Mahar MT. Accuracy of intensity and inclinometer output of three activity monitors for identification of sedentary behavior and light-intensity activity. *J Obes*. **2012**;2012:460271.
22. Chastin SF, Ferriolli E, Stephens NA, Fearon KC, Greig C. Relationship between sedentary behaviour, physical activity, muscle quality and body composition in healthy older adults. *Age Ageing*. **2012**;41:111-114.
23. Chastin SF, Granat MH. Methods for objective measure, quantification and analysis of sedentary behaviour and inactivity. *Gait Posture*. **2010**;31:82-86.
24. van Nassau F, Chau JY, Lakerveld J, Bauman AE, van der Ploeg HP. Validity and responsiveness of four measures of occupational sitting and standing. *Int J Behav Nutr Phys Act*. **2015**;12:144.
25. Buckley JP, Mellor DD, Morris M, Joseph F. Standing-based office work shows encouraging signs of attenuating post-prandial glycaemic excursion. *Occup Environ Med*. **2014**;71:109-111.
26. Judice PB, Hamilton MT, Sardinha LB, Zderic TW, Silva AM. What is the metabolic and energy cost of sitting, standing and sit/stand transitions? *Eur J Appl Physiol*. **2016**;116:263-273.
27. Mansoubi M, Pearson N, Clemes SA, Biddle SJ, Bodicoat DH, et al. Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour. *BMC Public Health*. **2015**;15:516.
28. Fullerton S, Taylor AW, Dal Grande E, Berry N. Measuring physical inactivity: do current measures provide an accurate view of "sedentary" video game time? *J Obes*. **2014**;2014:287013.
29. Owen N. Ambulatory monitoring and sedentary behaviour: a population-health perspective. *Physiol Meas*. **2012**;33:1801-1810.
30. Boerema ST, Essink GB, Tonis TM, van Velsen L, Hermens HJ. Sedentary Behaviour Profiling of Office Workers: A Sensitivity Analysis of Sedentary Cut-Points. *Sensors*. **2015**;16:22.