



Universidad Autónoma
de Madrid

Biblos-e Archivo
Repositorio Institucional UAM

Repositorio Institucional de la Universidad Autónoma de Madrid

<https://repositorio.uam.es>

Esta es la **versión de autor** del artículo publicado en:

This is an **author produced version** of a paper published in:

Journal of Physical Activity and Health 17.1 (2020): 2 – 12

DOI: <https://doi.org/10.1123/jpah.2019-0145>

Copyright: © 2020 Human Kinetics

El acceso a la versión del editor puede requerir la suscripción del recurso

Access to the published version may require subscription

Criterion validity of the sedentary behavior question from the Global Physical Activity Questionnaire (GPAQ) in Older Adults

Miguel A. de la Cámara¹, Sara Higuera-Fresnillo¹, Verónica Cabanas-Sánchez¹, Kabir P. Sadarangani^{2,3}, David Martinez-Gomez^{1,4}, Óscar L. Veiga¹

¹Department of Physical Education, Sport and Human Movement. Faculty of Teacher Training and Education, Autonomous University of Madrid, Spain.

²School of Physiotherapy. Faculty of Health Sciences. San Sebastian University, Santiago, Chile.

³Master of Clinical Exercise Physiology. Faculty of Sciences, Mayor University, Chile.

⁴IMDEA Food Institute. CEI UAM + CSIC, Madrid, Spain.

Corresponding author:

Miguel Ángel de la Cámara. Department of Physical Education, Sport and Human Movement. Facultad de Formación de Profesorado y Educación. Universidad Autónoma de Madrid. Ctra. de Colmenar Km 11. 28049. Madrid (Spain). Tf: +34 914972115. Fax: +34 914974484. E-mail: miguel.camara@uah.es

Word count (main text): 4353

Abstract word count: 200

Pages count: 28 (including title and references)

Number of Tables: 2

Number of Figures: 2

Number of appendix: 3

**Criterion validity of the sedentary behavior question from the Global Physical
Activity Questionnaire (GPAQ) in Older Adults**

Abstract

Background: The aim of this study was to assess the validity of the single question to determine sedentary behavior (SB) by using the Global Physical Activity Questionnaire (GPAQ) in older adults.

Methods: The sample included 163 participants (96 women), aged 65 to 92 years. Self-reported SB was obtained from the GPAQ. Objectively measured SB was assessed using the Intelligent Device for Energy Expenditure and Activity (IDEEA). Participants wore the IDEEA continuously during two consecutive days while following their daily routine. The relative validity was assessed using the Sperman rank correlation coefficient (ρ) and the agreement was examined using mean bias and 95% limit of agreement (LoA) with the IDEEA as reference.

Results: The results showed small correlations between the SB from the GPAQ and the objective measures ($\rho = 0.291$, $p < 0.001$) and ranged from $\rho = 0.217$ to $\rho = 0.491$ depending on the potential moderator. Likewise, the GPAQ underestimates the SB approximately 2 h/day in older adults (LoA = -7.3 to 3.4 h/day).

Conclusion: The GPAQ may not be the most suitable questionnaire for measuring SB in this population and should be used with caution, because those studies that use this questionnaire in older adults may have an inaccurate measurement of SB levels.

Keywords: Sedentary behaviour, older adults, questionnaires, GPAQ, IDEEA.

Background

Sedentary behavior (SB), defined as any waking behavior characterized by an energy expenditure ≤ 1.5 Metabolic Equivalents Tasks (METs) while in a sitting, reclining or lying posture¹, is a public health risk factor independent of moderate-to-vigorous physical activity^{2,3}. Older adults spend much of their waking time in SB (on average 8.5-9.6 h daily sitting time), and are the most sedentary age group⁴. Recent research highlights the deleterious impact of SB on health (e.g., cardiovascular diseases, metabolic syndrome, cancer, musculoskeletal diseases) and its relationship with mortality in older adults^{3,5}. It has been observed that older adults who spend more than 8 hours/day sitting present a higher risk of all-cause mortality than those who spend less than 8 hours/day sitting^{6,7}. However, SB appears to be more difficult to measure than physical activity (PA) and its measuring is currently a challenge regardless of the method used⁴.

Objective measures such as wearable accelerometers or activity monitors are gaining popularity in health research; however, they present several challenges and limitations when assessing sedentary time. For example, studies that use the ActiGraph-based <100 counts/minute cut-off point to determine SB may categorize time spent in light-intensity activities as standing in sitting time^{8,9}. Moreover, they may misclassify non-wear time (periods when persons may not be wearing their monitor, such as during sleeping, showering and aquatic activities, and periods when participants forget to reattach the monitor) as SB^{10,11}. Also, although some activity monitors measure sedentary time very accurately (e.g., ActivPAL, ActiGraph or GENEActiv)^{11,12}, most of them are unable to

distinguish among the postures included in the consensus definition of sedentary behavior (i.e., lying, reclining and sitting)¹ and in which older adults spend much of the day¹³.

On the other hand, self-report measures as questionnaires, despite their known limitations in older adults (recall bias, misinterpretation, susceptibility to fluctuations in health status or problems with memory and cognition)¹⁴, are widely used by practitioners, researchers and clinicians in order to study and examine the effectiveness of interventions and public health initiatives related to PA and SB. They can be implemented on a large scale, are relatively inexpensive, and do not alter participants' behavior under investigation^{11,12,15,16}. Also, they increase knowledge on SB because most of them include questions about time spent in different SB or sitting domains. However, self-report tools (e.g., single item, diaries/logs or questionnaires) show low correlation with objective data as well as low precision, error and bias¹⁷. It has been observed that they generally underestimate sedentary time in comparison to accelerometer data (>2 h/day)¹⁸⁻²⁵, showing weak to moderate correlations when they are compared with objective measurements^{18-21,25}.

The Global Physical Activity Questionnaire (GPAQ) is an instrument developed by the World Health Organization for monitoring physical activity in countries. It consists of 16 questions designed to estimate an individual's level of PA in three domains (activity at work, travel to and from places and recreational activities) as well as SB²⁶. In this questionnaire, self-reported sitting/reclining time is reported as representative of SB. Different studies showed that a single question for measuring SB has moderate to good reliability and moderate validity against accelerometers for estimating total sitting time in adults^{27,28}. For the single question of the GPAQ, two studies reported fair/poor correlation

and large differences when compared with ActiGraph for measuring SB in adults^{20,21}.

However, this question has not been validated in older adults.

High-quality measurement is essential in all elements of SB epidemiology, so that we can learn how SB may influence healthy aging^{29,30}. New sophisticated systems for determining postural allocation (i.e., sitting, reclining, lying, and standing) as the ActivPal or the IDEEA could provide more precise estimates of SB and they can be useful for validating questions on physical activity survey instruments that ask respondents to recall the amount of time spent as sitting³¹. This means that questionnaires can now be validated by more accurate instruments and the researchers have a great opportunity to study more confidently the validity of these questions. Therefore, the aim of this study was to assess the validity of the single question to determine SB by using the GPAQ (GPAQ-SB) in older adults.

Methods

Study participants

The sample comprised of 200 older adults (113 women) who participated in the IMPACT65+ study. This cross-sectional study was designed to examine the associations between objectively-measured physical behaviour and indicators of frailty, quality of life and health in apparently well-functioning community-dwelling adults aged 65 and older. Participants were recruited from senior and wellness centers located in Madrid (Spain).

Trained researchers conducted a face-to-face interview with each participant, obtaining information on sociodemographic characteristics, health status, daily life activities, PA and self-reported SB. Anthropometric measurements (i.e., body height, weight and waist circumference) were also taken. Finally, after the interview, each participant were fitted with the Intelligent Device for Energy Expenditure and Activity monitor (IDEEA) and were asked to continue their daily routines for the following two days.

Inclusion criteria for study were age ≥ 65 years, having physical independence to attend study and be non-institutionalized living in community. Participants were excluded if they had any medical, neurologic, or musculoskeletal condition that would hinder wearing the monitor or measurement (i.e., skin diseases, atopic or sensitive skin, tremors or muscular pain affecting daily life).

Informed consent was obtained from all participants. The study protocol was approved by the Research Ethics Committee of the Autonomous University of Madrid, Spain.

Self-reported SB

Self-reported SB was obtained from the GPAQ in a face-to-face interview. The time spent in SB was obtained by asking the GPAQ-SB single-item question: “How much time do you usually spend sitting or reclining on a typical day?” They were requested to report, as indicated the GPAQ’s guideline, the time spent sitting or reclining at work, at home, getting to and from places, or with friends, including time spent: sitting at a desk, sitting with friends, travelling in car, bus, train, reading, playing cards or watching television, but they should not include time spent sleeping. This time was reported in hours per day (h/day).

Objectively-measured SB

Objectively measured SB was assessed using the IDEEA 3 (MiniSun LLC, Fresno, CA) (see image in Appendix). This device is a portable gait and posture analysis system and physical activity monitor which is able to quantify daily activities in free-living conditions. The IDEEA 3 detects over 40 different physical activities and postures, such as sitting, reclining, lying and standing, with 91.6% accuracy, and could identify 96% of sitting activities out of a total of 97% of the monitored sitting time³². It consists of five small sensors (size; 18.0 x 15.0 x 2.9 mm) that are attached to the body with porous hypoallergic medical tape, two small data collectors, called subrecorders (size; 4.0 x 2.3 x 1.1 cm) that are worn on the ankle and a main recorder 32-bit microprocessor (size; 7.8 x 5.5 x 1.9 cm) that is worn on the waist. The five sensors can measure body-segment angles and movement (acceleration) in 3 orthogonal directions. Sensors were attached following the manufacturer’s instructions: (i) one sensor was attached to the center of the participant’s sternum, just below the sternal angle and vertical to the x axis, (ii) two on the front of each thigh, on the front sides of the upper legs, halfway between the hip and knee, and (iii) two in the underside of each foot on the outside arch and proximal to the head of the fourth

metatarsal³³. The output signals from the sternum and thigh sensors travel through thin flexible cables to the main recorder device, while the output signal from the both feet send data wirelessly to facilitate motion during activity.

For this study, we used three activity patterns detected by the IDEEA 3 related to SB (i.e., sitting, reclining and lying postures during waking time). The sum of these postures was reported as representative of SB from the IDEEA 3 (IDEEA-SB). In addition, because the GPAQ-SB question refers specifically to sitting or reclining postures, we performed independent analyses for sitting and the sum of sitting and reclining postures from the IDEEA 3 (IDEEA sitting time and IDEEA sitting + reclining, respectively). Sleep period time was identified by an automated algorithm (algorithm #7) which was developed for the IDEEA using Visual Basic for Applications. The algorithm achieved a high level of agreement in determining sleep time when compared to self-reported data (accuracy=95.3%; sensitivity=94.7%; specificity=96.0%) and expert visual analysis (accuracy=97.7%; sensitivity=96.4%; specificity=98.6%)³⁴.

Participants wore the IDEEA 3 continuously during two consecutive days, as the battery life is less than 60 hours. Data were collected on days between Monday and Saturday while the participants followed their daily routine and it was placed and removed by the researchers. Sunday was not included because the opening hours of the recruitment centers were limited from Monday to Saturday. Therefore, participants wore the IDEEA 3 from Monday to Wednesday or from Thursday to Saturday. A previous study showed that this methodology is feasible because the inter-day variability for sitting posture is very low in this population (<5% between two measurement days), showing that there were no statistically significant differences between measurements days ($p=0.261$)³⁵. The device is not water resistant and each participant was informed that they could not perform aquatic

activities or shower during that period. Moreover, we provided participants with written placement instructions to take away with them in addition to the verbal instructions. The IDEEA 3 was set up using each participant's weight, height, age, and sex and calibrated individually following the IDEEA software instructions. Data were collected at 32 Hz and the IDEEA 3 started data recording as soon as it was fitted and calibrated. Data were downloaded using ActView™ software for processing (MiniSun LLC, Fresno, CA) (see <http://www.minisun.com/ideea.htm>). Data from participants who did not provide at least 10 hours of waking time per day (minimum validity period of monitoring considered adequate for estimating habitual behaviour) were not included in the analyses.

Other measures

Socio-demographic characteristics (i.e., sex, age and educational level), health-related, body mass index (BMI), chronic conditions, frailty, physical functioning, and PA were obtained in the initial interview. They were considered potential moderators that might influence in the validity of GPAQ-SB. Thus, in order to analyze their influence, we studied two groups for each potential moderator: age (i.e., 65-70 and >70 years), educational level (i.e., less than high school and high school or higher), BMI (i.e., not obese and obese according to the cut-off point 30 kg/m^2 ³⁶), health status (i.e., no chronic conditions and 1 or more chronic condition according to the following diseases diagnosed by a physician: coronary heart disease, stroke, asthma, rheumatism, hip fracture, cancer, Parkinson, and dementia or Alzheimer), frailty (i.e., robust, and pre-frail or frail, according to the Fried frailty criteria ³⁷), and METs-hour/week of PA (i.e., below to the median and above to the median).

Statistical analyses

Descriptive characteristics of the study sample were described as median and interquartile range (IQR) and percentage. Data from both GPAQ-SB and the IDEEA 3 were reported as hours/day. Differences between the GPAQ-SB and the IDEEA 3 were tested by paired t tests. Unpaired t tests were used to determine mean differences by sex, education level, frailty, age, BMI, chronic condition, and PA groups. The relative validity was assessed using the Spearman rank correlation coefficient (ρ). The magnitude of the association was interpreted using Cohen's criteria: insubstantial (<0.10), small (0.10 to 0.30), moderate (0.30 to 0.50) and large (>0.50)³⁸. Correlation-coefficient differences between potential moderators were tested using Fisher's z transformation. Also, the absolute agreement between both methods was examined graphically using mean bias and a 95% limit of agreement (LoA) from the Bland-Altman plot with the IDEEA 3 as reference. All analyses were performed using SPSS Statistics 22 for Windows (IBM, Armonk, New York), with level of significance set at $p < 0.05$.

Results

From the initial 200 participants, 163 (96 women) provided valid data in both GPAQ-SB and the IDEEA 3 data (36 participants were excluded by the criteria of at least 10 hours of waking time per day). The age range of participants was 65-92 years. They wore the IDEEA 3 an average of 42.9 hours. Characteristics of the participants are described in Table 1.

Figure 1 shows differences and relationships between self-reported GPAQ-SB and the IDEEA-sitting time, the IDEEA-sitting + reclining and the IDEEA-SB measures. Median GPAQ-SB was 5.0 h/day (IQR 3.0-7.0), showing statistically significant differences with the IDEEA-sitting time [5.8 h/day (IQR 4.5-7.3), $p=0.026$], the IDEEA-sitting + reclining [6.4 h/day (IQR 5.1-7.4), $p<0.001$] and the IDEEA-SB [7.2 h/day (IQR 6.0-8.4), $p<0.001$]. There were no correlations between the GPAQ-SB and the IDEEA-sitting time, however, small-fair correlations were observed between the GPAQ-SB and the IDEEA-sitting + reclining and the IDEEA-SB (Figure 1).

The mean bias was between -1 and -2 h/day when compared the GPAQ-SB and the IDEEA-sitting + reclining and the IDEEA-SB, respectively, showing wide LoA (-6.7 to 4.4 h/day for sitting + reclining and -7.3 to 3.4 h/day for SB). However, when comparing the GPAQ-SB with the IDEEA-sitting time the mean bias was lower (-0.6 h/day), but we also found broad LoA (-6.75 to 5.64 h/day) (Figure 2). Moreover, Figure 2 shows the absolute agreement between the GPAQ-SB and the IDEEA 3 by groups-based on potential moderators. It was found several differences between them. The highest differences were observed for sex, obesity and PA when comparing the GPAQ-SB and the IDEEA sitting time and the IDEEA-sitting + reclining. However, when compared the GPAQ-SB with the

IDEEA-SB differences between mean bias were smaller for the different groups-based on potential moderators.

Table 2 shows the differences of the means between the GPAQ-SB and the IDEEA 3 by potential moderators. Statistically significant differences were found in all groups, based on potentials moderators when comparing the GPAQ-SB and the IDEEA-sitting + reclining and the IDEEA-SB. However, when the GPAQ-SB was compared with the IDEEA-sitting, no statistically significant differences were found by age, in women, and in participants of lower education level, and obese, frail or that engage in less physical activity. Furthermore, Table 2 shows the correlations between the GPAQ-SB and the IDEEA 3 measured by potential moderators. The GPAQ-SB and the IDEEA-sitting time showed statistically significant correlations in participants with higher educational level, in obese and not frail participants (relationships ranged from $r=0.257$ to $r=0.385$). When the associations were analyzed between the GPAQ-SB and the IDEEA-sitting + reclining time, the number of significant correlations increase, showing statistically significant correlations in participants aged >70 years, with higher educational level, obese participants, or those with chronic conditions and those who performed less PA (relationships ranged from $r=0.263$ to $r=0.370$). However, the number of correlations were higher and stronger when the analyses was performed between the GPAQ-SB and the IDEEA-SB (relationships ranged from $r=0.217$ to $r=0.491$), showing no association only in the non-obese and those who performed PA above the median. Finally, Fisher's z transformation test indicated statistically significant difference by educational level, chronic condition and BMI for the correlation coefficients derived from the correlations between the GPAQ-SB and the IDEEA-sitting time, the IDEEA-sitting + reclining and the IDEEA-SB, respectively.

Discussion

As far as we know, this is the first study to use a multi-sensor pattern-recognition activity monitor to validate SB derived from the GPAQ in older adults. This activity monitor helps detect postures defined in the Sedentary Behavior Research Network (SBRN) ¹ that other devices cannot detect. The results showed small correlations between the SB from the GPAQ and the objective measures. Likewise, the GPAQ underestimates the SB approximately 2 h/day in older adults. This underestimation could have important implication for research and practice, because it influences the interpretation of studies using this self-report method. Consequently, the single question to determine SB from the GPAQ may not be the most suitable for measuring SB in this population and should be used with caution.

The underestimation of SB observed with the GPAQ could have important implication

The GPAQ has been validated in multiple settings (urban and rural), populations (young and adults from different countries) and with different administration format ^{19,25,39}. The underestimation of SB observed in this study are consistent with previous studies and suggest that SB is underestimated when self-reported methods are used ⁴⁰. However, these results are considerably lower than other validity studies where the GPAQ was used in the general population, and where of underestimations between 4.9 and 10.3 h/day were observed ^{18,19,21,23,25}. These large differences could be explained in part by the age of the participants. In older adults, sedentary behaviors such as sitting show very low inter-day variability, and so this type of activity patterns may occur repeatedly in this population ³⁵. Therefore, when older adults are asked about SB, they may be more likely to remember this type of behavior.

Another possible explanation for these differences may be related with the type of objective measuring devices used as standard criterion in the previous validity studies. Most of them have used accelerometers such as the ActiGraph to measure SB, however it is not considered a gold-standard criterion for SB because they cannot detect postures²². Moreover, these studies are based on the widely used <100-cpm cut-off point to derive SB; however, it has been shown that the use of this cut-off point could be inaccurate for assessing SB compared to activity monitors such as ActivPAL⁴¹, which is able to detect postures. Furthermore, no studies have validated this cut-off point in older adults and it may be overestimating or underestimating their SB, making these accelerometers inaccurate for this purpose when they are based in this cut-off point. Another, lower cut-off point (<50 cpm) has been suggested as the most appropriate for discerning SB in older adults⁴⁰. Currently it is a focus of discussion and an emerging area of research in this population^{12,22,42}.

The results of this study show small correlation between the GPAQ-SB and the SB measured by the IDEEA 3 ($r=0.29$). However, this correlation is stronger than that of a previously published questionnaire designed specifically for older adults: the Community Healthy Activities Model Program for Seniors (CHAMPS)⁴³. This questionnaire includes several questions referred to different sitting domains (watching TV, reading, sitting and talking with friends, ride in a car, traveling, etc.); however, it showed small correlation with objective measurements ($r=0.12$). It seems possible that this result would be due to the objective measures used as standard criterion (ActiGraph), commented above, as well as the questionnaire design, which has question that have a weekly limit (i.e, maximum 9 hours per week)⁴³. This fact can affect the total SB reported by older adults and not show the reality of their behavior.

However, the correlation of the current study is lower than previous research carried out in other European countries with the GPAQ. In the study of Wanner and Colleagues the correlation between the GPAQ-SB and objective measures (ActiGraph) was higher ($r=0.37$) in the subsample of participants aged 60 years and older²⁵. The differences could be attributed to the self-administered format, suggesting that this mode may allow participants to have more time to think about their SB than in an interview format as used in our study²⁵. This phenomenon was documented by Chu and colleagues, who observed that SB from the self-administered format of the GPAQ was moderately correlated with the accelerometry-based SB ($r=0.46$), but the SB from the interviewer-administration of the GPAQ was poorly correlated with accelerometry SB data ($r=0.12$)⁴⁴. Similarly, other PA questionnaires such as the International Physical Activity Questionnaire (IPAQ) also showed moderate correlations with objective measures when it was self-administered in older adults ($r=0.36$ and $r=0.29$ when it was compared with the ActiGraph and GENEActiv accelerometers)^{45,46}.

In addition, the design of the SB question of the GPAQ (consisting in a single-item question) could explain the poor correlation between methods. Studies performed in older adults with more than one sitting domain indicated better correlation with self-reported SB when it was compared with objective measures^{11,24,30}, suggesting that a single-item question to measure sitting time may be worse than the use of several questions that include different sitting-domains. Previous research indicated that the measured sedentary time would be more accurate if researchers agreed on the taxonomy of SB, clarified the sitting domains or provided examples relevant to older adults⁴⁰. The results of this study suggest that a single-item question to measure SB may not be accurate to assess SB in older adults.

Likewise, the single item of the GPAQ-SB includes two types of SB postures such as sitting/reclining, which should be taken in to account. Other validity studies used objective measures that cannot determine specifically both postures and therefore, we must be careful with their interpretation because they may not be a gold standard method for this goal. In this study, we used the IDEEA 3, which is able to identify sitting and reclining time with an accuracy of >99 and 96% respectively ³³, and is a suitable device to validate this questionnaire. For this study, the sum of both postures derived from the IDEEA 3 might have been thought to have the strongest correlation. Contrary to expectations, the highest correlations were with the total SB (sum of sitting, reclining and lying postures during waking time) derived from the IDEEA 3. It is possible to hypothesize that it may be difficult for older adults to distinguish between reclining and lying postures, and therefore they may have reported time spent lying as reclining. Likewise, and taking to account that the SBRN includes waking time in lying posture as SB ¹, it would be interesting to introduce this posture in the question. Further research is needed to examine more closely this important issue.

In addition, results from this validity study suggest several findings that should be taken into account. On the one hand, although no statistically significant differences were found between men and women, the correlation between the GPAQ-SB and the IDEEA-SB was moderately correlated in men and poorly in women. This finding had not previously been described in older adults, therefore, more research is needed to explore whether these correlations are consistent in order to establish, as suggested in the literature, whether there may be sex differences in accuracy of self-reported SB⁴⁷. On the other hand, our study also found that BMI may be a factor capable of affecting the validity of the GPAQ-SB.

Sedentary behavior vary by BMI in older adults, showing that obese spend more time on

this behavior⁴⁸. This factor may explain the different correlations between obese and non-obese because it may be easier for the obese to remember their sedentary time. This should be investigated and must be considered because it may be possible to cause bias⁴⁴.

For this study, we used the time spent on average per day in SB from 48 hours monitoring time, while researchers have converged on a measurement protocol of seven consecutive days of accelerometer monitoring as an appropriate benchmark of PA assessment⁴⁹. Therefore, the monitoring time may not show a reliable estimate of weekly sitting time. However, previous research showed that between two and five monitoring days are enough to estimate SB in older adults^{50,51}. This has been observed with the IDEEA 3, which showed that to achieve ICC ≥ 0.80 for sitting posture, only 2 days of monitoring may be needed in this population³⁵, being substantially lower than the monitoring time needed using others accelerometers. Furthermore, it has been suggested that the adherence to study protocols may decrease with more monitoring days in this population, showing that 7-day accelerometer protocol has lower adherence (43.8%) than for 2 days (85.3%)⁵². In addition, considering that the GPAQ-SB single-item question refers only to time spend sitting or reclining on a typical day, the monitoring time is enough to use for this validity study. However, it has been suggested that SB could vary depending on which days of the week are examined. While Hart et al.⁵³ proposed that day of the week cannot be completely ignored in the design and analysis of studies that involve < 7-day monitoring protocols, more recently, literature has emerged that offers contradictory findings showing that there are no differences in the SB estimates between weekdays and weekend days⁵¹.

There are several limitations to this study. The monitoring time was limited to 48 hours because the battery life of the IDEEA 3 is short, meaning the device cannot be used for longer periods to provide more reliable data. Due to the short monitoring time, it is

possible that there is some sort of reactivity to wearing the device, which can in turn influence behaviors. Moreover, the sleep period was identified using an algorithm based on variations of activity type, speed, intensity and gait curves throughout the day³⁴. This algorithm has been validated against self-reported measures and expert visual analysis of raw data showing high levels of agreement; however, the algorithm has been not contrasted against polysomnography (the gold standard for sleep measurement) and therefore, some SB may have been misclassified as sleep time or *vice versa*. Furthermore, the participants were instructed to not undertake any aquatic activities while wearing the device, therefore this would have influenced the amount of sedentary time that individuals engaged in if someone regularly swam. However, strengths of the current study include the use of a multi-sensor pattern-recognition activity monitor during 24-h monitoring. Unlike other accelerometers commonly used for the validation of questionnaires, such as ActiGraph and ActivPAL, the IDEEA 3 is able to detect specifically sitting and reclining postures and is the only one that is able to provide data based on the conceptual model of movement-based terminology arranged around a 24-h period¹.

The purpose of the current study was to assess the validity of the single question to determine SB from the GPAQ in older adults. The results of this study indicated that the GPAQ underestimate the SB in this population by around 2 hours per day. Moreover, its poor correlation with the standard criterion shows that this question may not be the most suitable one for measuring sedentary time in older adults. The results of this study are interesting to those epidemiological or intervention studies that use this questionnaire in older adults, because an inaccurate measurement of SB levels might reduce the associations or present bias when it is related with health.

Acknowledgments and funding

This work was supported by Grants from MINECO I+D+i (DEP2013-47786-R), UAM-Santander (CEAL-AL/2015-20), and Real Madrid-UEM (P2016/RM09). SHF and MAC were supported by FPI grants from Autonomous University of Madrid. DMG is supported by a "Ramón y Cajal" contract (RYC-2016-20546). The funding organizations had no role in the study design; the collection, analysis, or interpretation of the data; or the decision to submit the manuscript for publication.

Competing interest

None of the authors declares competing financial interests.

References

1. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary Behavior Research Network (SBRN) - Terminology Consensus Project process and outcome. *Int J Behav Nutr Phys Act.* 2017;14(1):75. doi:10.1186/s12966-017-0525-8.
2. Gibbs BB, Hergenroeder AL, Katzmarzyk PT, Lee I-M, Jakicic JM. Definition, measurement, and health risks associated with sedentary behavior. *Med Sci Sports Exerc.* 2015;47(6):1295-1300. doi:10.1249/MSS.0000000000000517.
3. de Rezende LFM, Rey-Lopez JP, Matsudo VKR, do Carmo Luiz O. Sedentary behavior and health outcomes among older adults: a systematic review. *BMC Public Health.* 2014;14:333. doi:10.1186/1471-2458-14-333.
4. Wullems JA, Verschueren SMP, Degens H, Morse CI, Onambele GL. A review of the assessment and prevalence of sedentarism in older adults, its physiology/health impact and non-exercise mobility counter-measures. *Biogerontology.* 2016;17(3):547-565. doi:10.1007/s10522-016-9640-1.
5. Wirth K, Klenk J, Brefka S, et al. Biomarkers associated with sedentary behaviour in older adults: A systematic review. *Ageing Res Rev.* 2017;35:87-111.

doi:10.1016/j.arr.2016.12.002.

6. Pavey TG, Peeters GG, Brown WJ. Sitting-time and 9-year all-cause mortality in older women. *Br J Sports Med.* 2015;49(2):95-99. doi:10.1136/bjsports-2012-091676.
7. Martinez-Gomez D, Guallar-Castillon P, Leon-Munoz LM, Lopez-Garcia E, Rodriguez-Artalejo F. Combined impact of traditional and non-traditional health behaviors on mortality: a national prospective cohort study in Spanish older adults. *BMC Med.* 2013;11:47. doi:10.1186/1741-7015-11-47.
8. Crouter SE, DellaValle DM, Haas JD, Frongillo EA, Bassett DR. Validity of ActiGraph 2-regression model, Matthews cut-points, and NHANES cut-points for assessing free-living physical activity. *J Phys Act Health.* 2013;10(4):504-514.
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(8):1561-1567. doi:10.1249/MSS.0b013e31820ce174.
10. Winkler EAH, Gardiner PA, Clark BK, Matthews CE, Owen N, Healy GN. Identifying sedentary time using automated estimates of accelerometer wear time. *Br J Sports Med.* 2012;46(6):436-442. doi:10.1136/bjsm.2010.079699.
11. Healy GN, Clark BK, Winkler EAH, Gardiner PA, Brown WJ, Matthews CE. Measurement of adults' sedentary time in population-based studies. *Am J Prev Med.* 2011;41(2):216-227. doi:10.1016/j.amepre.2011.05.005.
12. Schrack JA, Cooper R, Koster A, et al. Assessing daily physical activity in older adults: Unraveling the complexity of monitors, measures, and methods. *Journals Gerontol - Ser A Biol Sci Med Sci.* 2016;71(8):1039-1048. doi:10.1093/gerona/glw026.

13. De la Camara MÁ, Higuera-Fresnillo S, Martinez-Gomez D, Veiga OL. Daily activities assessed by a high-tech pattern-recognition monitor in older adults: preliminary findings from the IMPACT65+ study. *Rev Esp Geriatr Gerontol*. July 2018. doi:10.1016/j.regg.2018.01.006.
14. Kowalski K, Rhodes R, Naylor P-J, Tuokko H, MacDonald S. Direct and indirect measurement of physical activity in older adults: a systematic review of the literature. *Int J Behav Nutr Phys Act*. 2012;9:148. doi:10.1186/1479-5868-9-148.
15. Dyrstad SM, Hansen BH, Holme IM, Anderssen SA. Comparison of self-reported versus accelerometer-measured physical activity. *Med Sci Sports Exerc*. 2014;46(1):99-106. doi:10.1249/MSS.0b013e3182a0595f.
16. Dowd KP, Szeklicki R, Minetto MA, et al. A systematic literature review of reviews on techniques for physical activity measurement in adults: a DEDIPAC study. *Int J Behav Nutr Phys Act*. 2018;15(1):15. doi:10.1186/s12966-017-0636-2.
17. Chastin SFM, Dontje ML, Skelton DA, et al. Systematic comparative validation of self-report measures of sedentary time against an objective measure of postural sitting (activPAL). *Int J Behav Nutr Phys Act*. 2018;15(1):21. doi:10.1186/s12966-018-0652-x.
18. Hoos T, Espinoza N, Marshall S, Arredondo EM. Validity of the Global Physical Activity Questionnaire (GPAQ) in adult Latinas. *J Phys Act Health*. 2012;9(5):698-705.
19. Mumu SJ, Ali L, Barnett A, Merom D. Validity of the global physical activity questionnaire (GPAQ) in Bangladesh. *BMC Public Health*. 2017;17(1):650. doi:10.1186/s12889-017-4666-0.
20. Aguilar-Farias N, Leppe Zamora J. Is a single question of the Global Physical

- Activity Questionnaire (GPAQ) valid for measuring sedentary behaviour in the Chilean population? *J Sports Sci.* 2017;35(16):1652-1657.
doi:10.1080/02640414.2016.1229010.
21. Cleland CL, Hunter RF, Kee F, Cupples ME, Sallis JF, Tully MA. Validity of the global physical activity questionnaire (GPAQ) in assessing levels and change in moderate-vigorous physical activity and sedentary behaviour. *BMC Public Health.* 2014;14:1255. doi:10.1186/1471-2458-14-1255.
 22. Gardiner PA, Clark BK, Healy GN, Eakin EG, Winkler EAH, Owen N. Measuring older adults' sedentary time: reliability, validity, and responsiveness. *Med Sci Sports Exerc.* 2011;43(11):2127-2133. doi:10.1249/MSS.0b013e31821b94f7.
 23. Aguilar-Farias N, Brown WJ, Olds TS, Geeske Peeters GMEE. Validity of self-report methods for measuring sedentary behaviour in older adults. *J Sci Med Sport.* 2015;18(6):662-666. doi:10.1016/j.jsams.2014.08.004.
 24. Clark BK, Lynch BM, Winkler EA, et al. Validity of a multi-context sitting questionnaire across demographically diverse population groups: AusDiab3. *Int J Behav Nutr Phys Act.* 2015;12:148. doi:10.1186/s12966-015-0309-y.
 25. Wanner M, Hartmann C, Pestoni G, Martin BW, Siegrist M, Martin-Diener E. Validation of the Global Physical Activity Questionnaire for self-administration in a European context. *BMJ open Sport Exerc Med.* 2017;3(1):e000206.
doi:10.1136/bmjsem-2016-000206.
 26. Armstrong T, Bull F. Development of the World Health Organization Global Physical Activity Questionnaire (GPAQ). *J Public Health (Bangkok).* 2006;14(2):66-70. doi:10.1007/s10389-006-0024-x.
 27. Clemes SA, David BM, Zhao Y, Han X, Brown W. Validity of two self-report

- measures of sitting time. *J Phys Act Health*. 2012;9(4):533-539.
28. Rosenberg DE, Bull FC, Marshall AL, Sallis JF, Bauman AE. Assessment of sedentary behavior with the International Physical Activity Questionnaire. *J Phys Act Health*. 2008;5 Suppl 1:S30-44.
 29. Atkin AJ, Gorely T, Clemes SA, et al. Methods of Measurement in epidemiology: Sedentary Behaviour. *Int J Epidemiol*. 2012;41(5):1460-1471.
<http://dx.doi.org/10.1093/ije/dys118>.
 30. Visser M, Koster A. Development of a questionnaire to assess sedentary time in older persons--a comparative study using accelerometry. *BMC Geriatr*. 2013;13:80.
doi:10.1186/1471-2318-13-80.
 31. Lee I-M. *Epidemiologic Methods in Physical Activity Studies*. Oxford University Press; 2008.
 32. Jiang Y, Larson JL. IDEEA activity monitor: validity of activity recognition for lying, reclining, sitting and standing. *Front Med*. 2013;7(1):126-131.
doi:10.1007/s11684-012-0236-0.
 33. Zhang K, Werner P, Sun M, Pi-Sunyer FX, Boozer CN. Measurement of human daily physical activity. *Obes Res*. 2003;11(1):33-40. doi:10.1038/oby.2003.7.
 34. Cabanas-Sanchez V, Higuera-Fresnillo S, De la Cámara MÁ, Veiga OL, Martinez-Gomez D. Automated algorithms for detecting sleep period time using a multi-sensor pattern-recognition activity monitor from 24-h free-living data in older adults. *Physiol Meas*. 2018;39(5):55002. doi:10.1088/1361-6579/aabf26.
 35. de la Cámara MÁ, Higuera-Fresnillo S, Martinez-Gomez D, Veiga ÓL. Inter-day Reliability of the IDEEA Activity Monitor for Measuring Movement and Non-Movement Behaviors in Older Adults. *J Aging Phys Act*. May 2018:1-33.

doi:10.1123/japa.2017-0365.

36. Gutierrez-Fisac JL, Lopez E, Banegas JR, Graciani A, Rodriguez-Artalejo F. Prevalence of overweight and obesity in elderly people in Spain. *Obes Res.* 2004;12(4):710-715. doi:10.1038/oby.2004.83.
37. Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci.* 2001;56(3):M146-56.
38. Cohen J. A power primer. *Psychol Bull.* 1992;112(1):155-159.
39. Chu AHY, Ng SHX, Koh D, Muller-Riemenschneider F. Reliability and Validity of the Self- and Interviewer-Administered Versions of the Global Physical Activity Questionnaire (GPAQ). *PLoS One.* 2015;10(9):e0136944. doi:10.1371/journal.pone.0136944.
40. Harvey JA, Chastin SFM, Skelton DA. How Sedentary are Older People? A Systematic Review of the Amount of Sedentary Behavior. *J Aging Phys Act.* 2015;23(3):471-487. doi:10.1123/japa.2014-0164.
41. Koster A, Shiroma EJ, Caserotti P, et al. Comparison of Sedentary Estimates between activPAL and Hip- and Wrist-Worn ActiGraph. *Med Sci Sports Exerc.* 2016;48(8):1514-1522. doi:10.1249/MSS.0000000000000924.
42. Gorman E, Hanson HM, Yang PH, Khan KM, Liu-Ambrose T, Ashe MC. Accelerometry analysis of physical activity and sedentary behavior in older adults: a systematic review and data analysis. *Eur Rev Aging Phys Act.* 2014;11:35-49. doi:10.1007/s11556-013-0132-x.
43. Hekler EB, Buman MP, Haskell WL, et al. Reliability and validity of CHAMPS self-reported sedentary-to-vigorous intensity physical activity in older adults. *J Phys Act Health.* 2012;9(2):225-236.

44. Chu AHY, Ng SHX, Koh D, Muller-Riemenschneider F. Domain-Specific Adult Sedentary Behaviour Questionnaire (ASBQ) and the GPAQ Single-Item Question: A Reliability and Validity Study in an Asian Population. *Int J Environ Res Public Health*. 2018;15(4). doi:10.3390/ijerph15040739.
45. Aadland E, Ylvisaker E. Reliability of objectively measured sedentary time and physical activity in adults. *PLoS One*. 2015;10(7):e0133296. doi:10.1371/journal.pone.0133296.
46. Grimm EK, Swartz AM, Hart T, Miller NE, Strath SJ. Comparison of the IPAQ-Short Form and accelerometry predictions of physical activity in older adults. *J Aging Phys Act*. 2012;20(1):64-79.
47. Copeland JL, Ashe MC, Biddle SJ, et al. Sedentary time in older adults: a critical review of measurement, associations with health, and interventions. *Br J Sports Med*. 2017;51(21):1539. doi:10.1136/bjsports-2016-097210.
48. Koolhaas CM, van Rooij FJA, Schoufour JD, et al. Objective Measures of Activity in the Elderly: Distribution and Associations With Demographic and Health Factors. *J Am Med Dir Assoc*. 2017;18(10):838-847. doi:10.1016/j.jamda.2017.04.017.
49. Wolff-Hughes DL, McClain JJ, Dodd KW, Berrigan D, Troiano RP. Number of accelerometer monitoring days needed for stable group-level estimates of activity. *Physiol Meas*. 2016;37(9):1447-1455. doi:10.1088/0967-3334/37/9/1447.
50. Bull FC, Maslin TS, Armstrong T. Global physical activity questionnaire (GPAQ): nine country reliability and validity study. *J Phys Act Health*. 2009;6(6):790-804.
51. Sasaki JE, Junior JH, Meneguci J, et al. Number of days required for reliably estimating physical activity and sedentary behaviour from accelerometer data in older adults. *J Sports Sci*. 2018;36(14):1572-1577.

doi:10.1080/02640414.2017.1403527.

52. Kocherginsky M, Huisingh-Scheetz M, Dale W, Lauderdale DS, Waite L. Measuring physical activity with hip accelerometry among U.S. older adults: how many days are enough? *PLoS One*. 2017;12(3):e0174739. doi:10.1371/journal.pone.0174739.
53. Hart TL, Swartz AM, Cashin SE, Strath SJ. How many days of monitoring predict physical activity and sedentary behaviour in older adults? *Int J Behav Nutr Phys Act*. 2011;8:62. doi:10.1186/1479-5868-8-62.

Table 1. Participant characteristics

	Total
<i>n</i>	163
Age, median years (IQR)	70 (67-75)
65-70, n (%) ^a	47.9
Sex (% male)	41.1
Education level, n (%)	
Illiterate	13 (8.0)
Primary studies	102 (62.6)
Secondary studies	21 (12.9)
Medium university studies/ vocational training	17 (10.4)
Higher university studies	10 (6.1)
Percentage with at least one IADLS ^b disability	14.1
Body mass index, kg/m ²	28.5
Normal (18-24.99 kg/m ²), n (%)	27 (16.6)
Overweight (25-29.99 kg/m ²), n (%)	78 (47.9)
Obese (≥ 30 kg/m ²), n (%)	58 (35.5)
Chronic conditions ^c , n (%)	
No chronic conditions	84 (51.5)
≥ 1 chronic conditions	79 (48.5)
Frailty syndrome ^d , n (%)	
Robust (no criteria present)	77 (47.2)
Pre-frailty (1 or 2 criteria present)	78 (47.9)
Pre-frailty or frailty (≥ 3 criteria)	8 (4.9)
Physical activity ^e , median of METs-hour/week (IQR)	70.5 (43.1-96.3)
Below median ^a	43.0 (33.3-61.1)
Above median ^a	96.1 (84.8-115)

IQR: interquartile range; ^asex specific; IADLS : Instrumental Activities of Daily Living Scale; ^bPercentage with at least 1 IADLS positive answer; ^cDiabetes, coronary heart disease, stroke, asthma, rheumatism, cancer, hip fracture, Parkinson's disease, and Alzheimer's or other dementia; ^dAccording to Fried frailty

criteria; ^aPhysical activity was obtained from the European Prospective to Investigation to Cancer and Nutrition questionnaire; METs: metabolic equivalent.

Table 2. Differences and relationships between self-reported sedentary time from the Global Physical Activity Questionnaire (GPAQ-SB) and sitting, sitting + reclining and sedentary behavior from the Intelligent Device for Energy Expenditure and Activity (IDEEA)

	n	GPAQ-SB	Median (IQR)			Rho Spearman		
			IDEEA			GPAQ-SB vs IDEEA		
			Sitting time	Sitting+ reclining	Sedentary behavior	Sitting time	Sitting+ reclining	Sedentary behavior
Sex								
Men	67	5 (4-7)	6.6 (5.1-8.1) ¹	7.4 (6.0-8.6) ¹	7.5 (6.3-8.4) ¹	0.118	0.203	0.337**
Women	96	4 (3-6)	5.2 (4.1-6.5)	6.6 (5.5-7.8)¹	7.0 (5.8-8.2) ¹	0.063	0.197	0.238*
Age								
≤70 years	78	4 (3-7)	5.5 (4.4-7.0)	6.6 (5.5-8.1) ¹	6.9 (5.6-8.4) ¹	0.195	0.177	0.243*
>70 years	85	5 (4-6)	6.0 (4.6-7.4)	7.2 (6.0-8.2) ¹	7.2 (6.4-8.3) ¹	0.058	0.287**	0.388***
Education level								
Less than High School	115	5 (4-6)	5.6 (4.3-7.2) ¹	6.9 (5.6-8.1) ¹	7.2 (5.8-8.5) ¹	0.012	0.154	0.217*
High School or higher	48	4 (3-7)	6.1 (4.9-7.6)	6.9 (5.8-8.0) ¹	7.1 (6.1-7.9) ¹	0.385**	0.361*	0.463**
Body Mass Index								
<30 kg/m ²	105	4 (3-6)	6.1 (4.8-7.5) ¹	7.1 (5.8-8.1) ¹	7.0 (5.7-7.9) ¹	0.083	0.151	0.156
≥30 kg/m ²	58	5 (4-8)	5.1 (4.0-6.7)	6.7 (5.5-8.0) ¹	7.6 (6.2-8.6) ¹	0.272*	0.370**	0.491***
Chronic conditions								
None	84	5 (4-7)	5.9 (4.4-7.2) ¹	6.8 (5.6-8.1) ¹	7.2 (5.8-8.1) ¹	0.041	0.092	0.217*
≥ 1	79	4 (3-6)	5.7 (4.5-7.5) ¹	7.1 (5.8-8.1) ¹	7.2 (6.1-8.6) ¹	0.187	0.347**	0.373**
Frailty syndrome								
Robust	77	5 (4-5)	6.0 (4.8-7.4) ¹	6.8 (5.6-8.1) ¹	7.0 (5.8-7.9) ¹	0.257*	0.202	0.237***
Pre-frail or frail	86	4 (3-7)	5.6 (4.2-7.2)	6.9 (5.6-7.9) ¹	7.4 (6.0-8.5) ¹	0.014	0.172	0.266*
Physical activity								
Below median	81	5 (4-8)	6.2 (4.6-7.3)	7.1 (5.8-8.3) ¹	7.6 (6.3-9.0) ¹	0.169	0.263**	0.337**
Above median	82	4 (3-5)	5.7 (4.5-7.3) ¹	6.7 (5.5-7.9) ¹	6.9 (5.6-7.9)¹	0.038	0.112	0.123

Note: Data are given in median hours/day and interquartile range (IQR); Data in bold denote statistically significance differences between groups ($p < 0.05$). ¹ Denote statistically significant differences in relation to sedentary time from GPAQ-SB. Asterisk denote that the correlation is statistically significant; * p-value < 0.01, ** p-value < 0.01, *** p-value < 0.001.

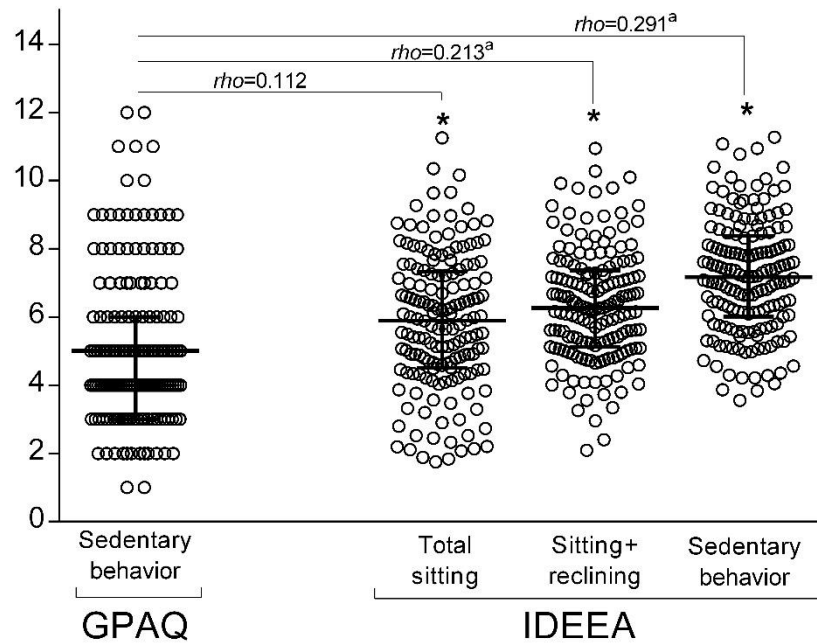


Figure 1. Mean differences and relationships (Spearman coefficient) between self-reported sedentary time from the Global Physical Activity Questionnaire (GPAQ) and total sitting time, sitting + reclining and sedentary behavior (sitting+reclining+lying) from the Intelligent Device for Energy Expenditure and Activity monitor (IDEEA); * Differences ($p<0.05$) between GPAQ and IDEEA; ^a Indicate p -value <0.05 .

Validity of the GPAQ sedentary behavior question

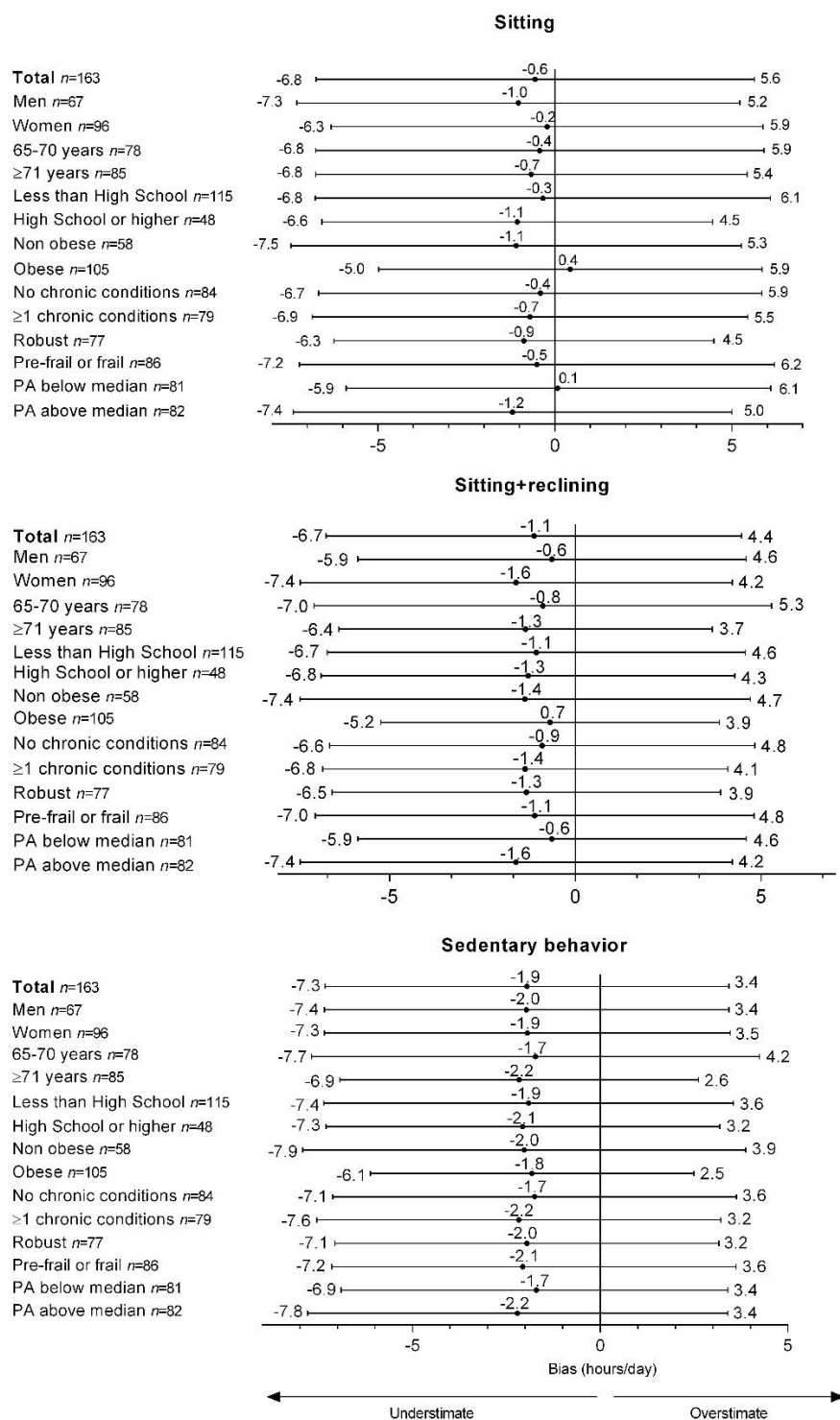
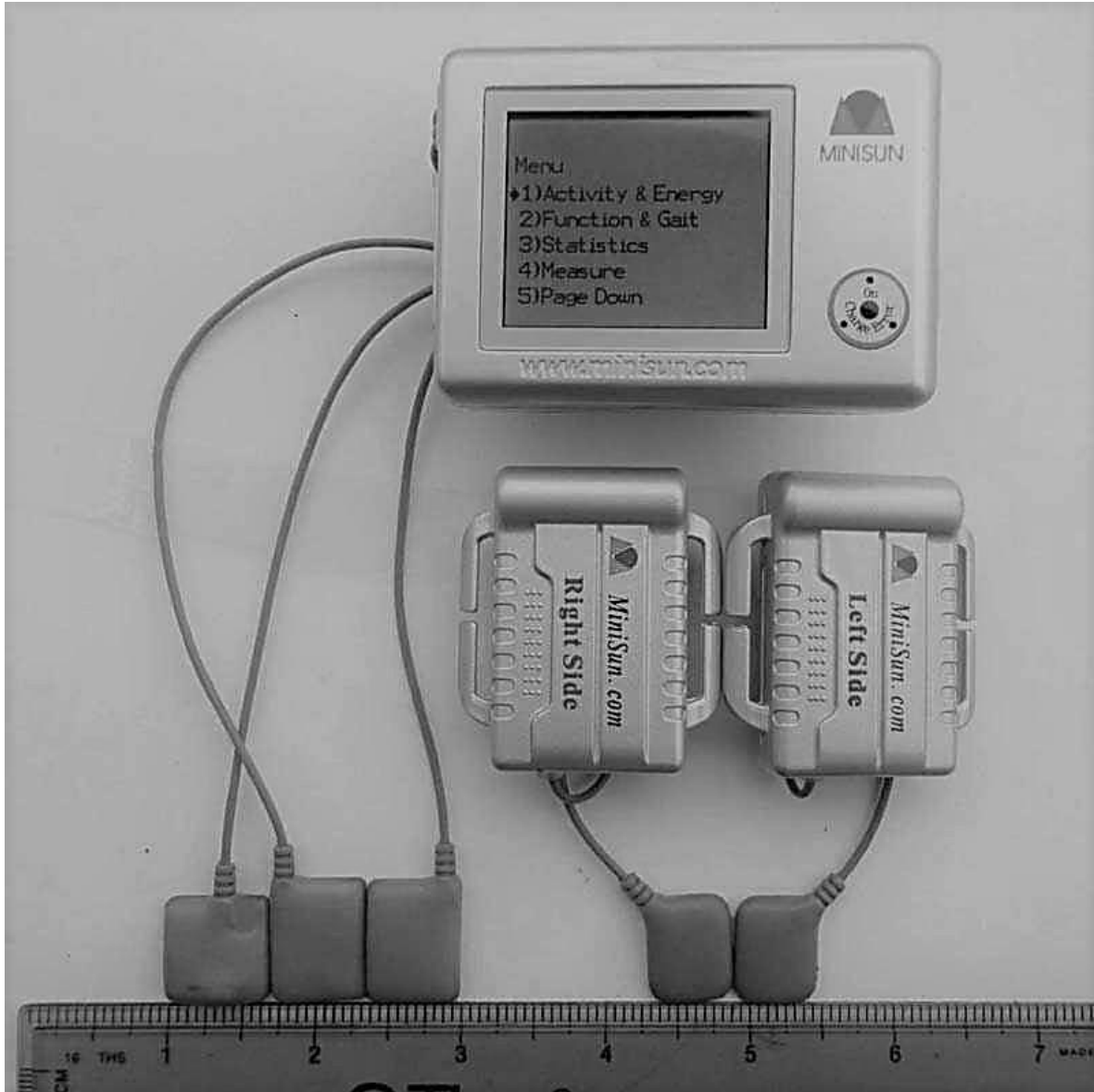


Figure 2. Plots of the differences between sedentary time from the Global Physical Activity Questionnaire (GPAQ-SB) with sitting time, sitting + reclining time and sedentary time

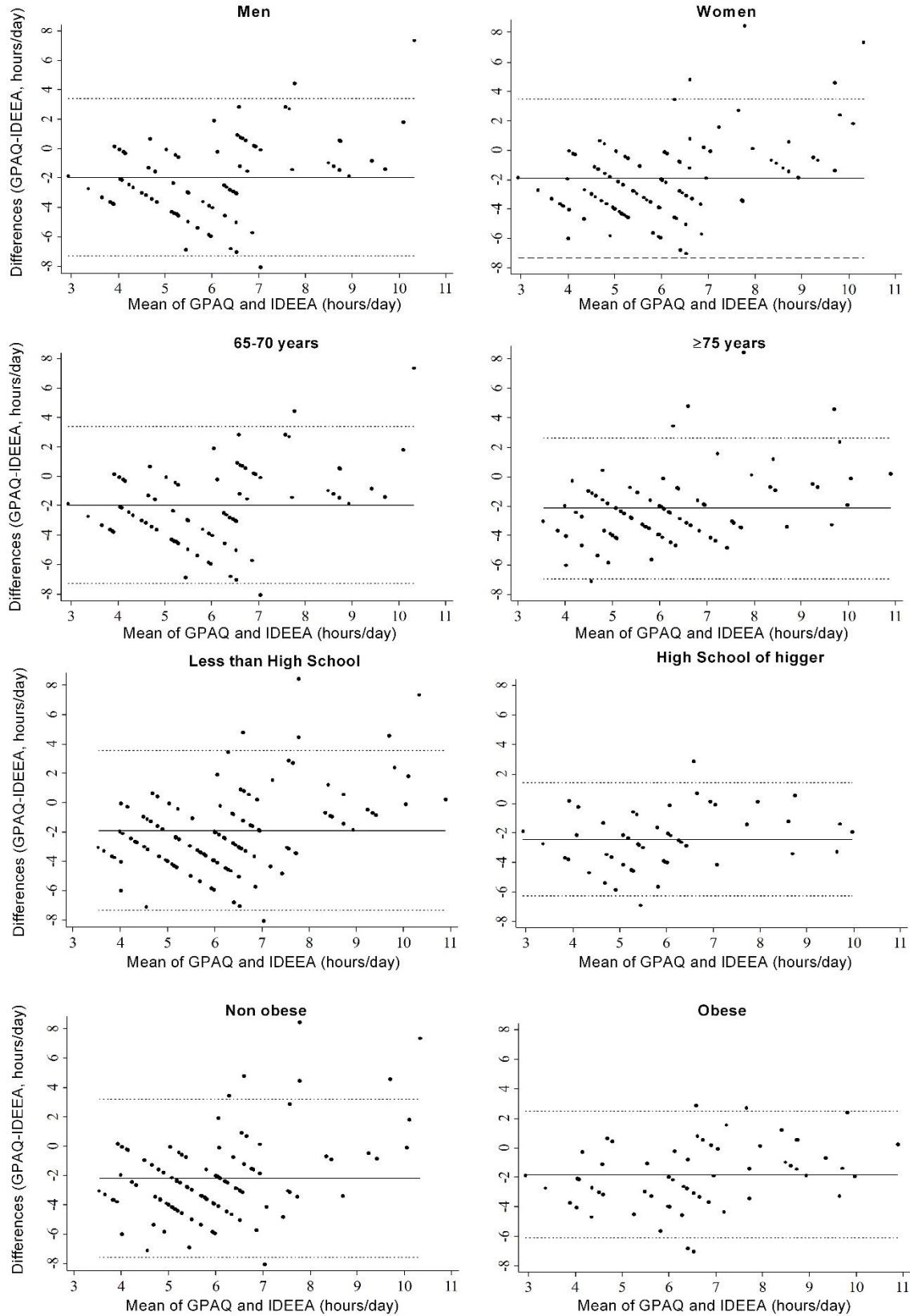
from the Intelligent Device for Energy Expenditure and Activity monitor (IDEEA); PA: physical activity; Dots represent the mean differences (hours/day) and bars the 95% limits of agreement between methods.

Appendix

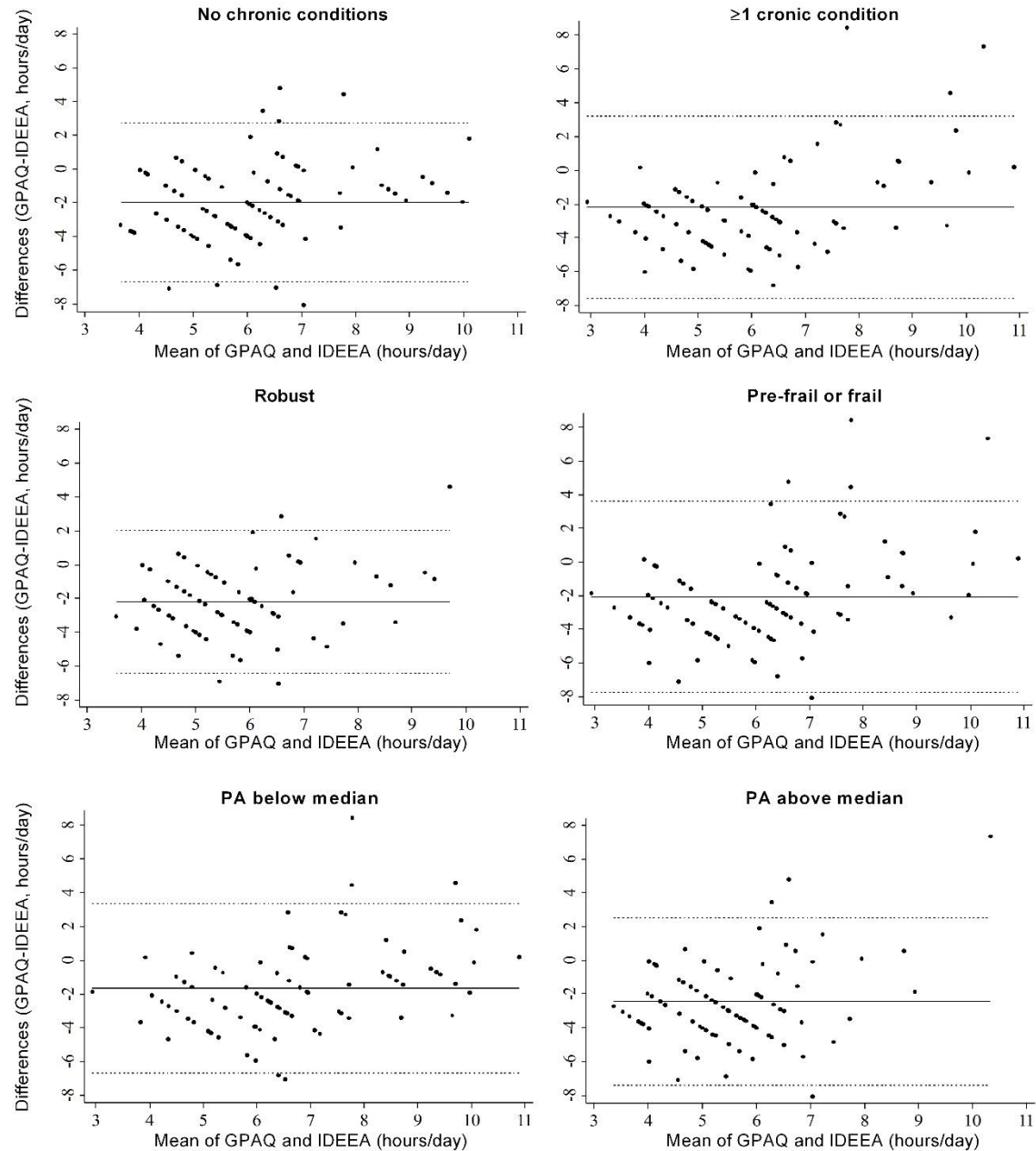


Appendix 1. Intelligent Device for Energy Expenditure and Activity (IDEEA, MiniSun LLC, CA, USA)

Validity of the GPAQ sedentary behavior question



Appendix 2. Bland-Altman Plots comparing sedentary time from self-reported Global Physical Activity Questionnaire (GPAQ) and the sedentary time from the Intelligent Device for Energy Expenditure and Activity monitor (IDEEA) for the different moderators.



Appendix 3. Bland-Altman Plots comparing sedentary time from self-reported Global Physical Activity Questionnaire (GPAQ) and the sedentary time from the Intelligent Device for Energy Expenditure and Activity monitor (IDEEA) for the different moderators.