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Intra-individual and inter-individual variability in daily sitting time and MVPA

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Abstract

Objectives—Little is known about how much variability exists in free-living sitting time within individuals. The purpose of this study was to examine intra-individual variability of objectively determined daily sitting time and to determine if this variability was related to weekly averages of sitting duration or recommended moderate-vigorous physical activity (MVPA). Also, this study determined the reliability of free-living sitting and MVPA time as it useful for guiding researchers in determining how many days of monitoring are needed.

Design—An activPAL monitor was worn for 7 consecutive days by 68 women (52±8 years).

Methods—Intra-individual range of daily sitting time was calculated. Generalizability theory analysis determined the reliability of daily sitting and recommended MVPA.

Results—Mean sitting time was 9.0±1.8 h/day and the within individual weekly mean range was 4.5±1.7 h/day. Similarly, there was a 4.5 h/day difference in sitting time between the mean of the lowest sitting (6.7±0.8) and highest sitting (11.3±1.1h/day) quartiles. The intra-individual range in daily sitting did not differ among quartiles of sitting time (i.e., 4.9±1.9, 4.1±1.9, 5.1±1.5, 3.9±1.1 h/day for the 1st–4th quartiles) nor among quartiles of MVPA (i.e., 4.2±1.8, 4.7±2.0, 4.6±1.5, 4.4±1.3 h/day for the 1st–4th quartiles). A reliability coefficient of 0.80 was achieved with 4 days of objectively measured sitting time and 7 days for MVPA.

Conclusions—The findings suggest exposure to relatively high levels of sedentary time may occur in people regardless of weekly averages in sitting and regular exercise due to the high day-to-day variation in daily sitting time (4.5 h/d range within a week).

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Keywords

sedentary behavior; inactivity; reliability; activPAL; posture; exercise

i. Introduction

Recent experimental studies indicate that variations in sitting time within one day have potent physiological effects including adverse exposure to cardiometabolic risk factors.[1,2] Studies in animals support rapid effects (i.e., <1 day) of muscular inactivity caused by a lack of low-intensity physical activity (LIPA) [3,4] that operate through mechanisms that are not just the opposite of more vigorous forms of physical activity.[5,6] Thus, variation in daily sitting time may be important for potentially adverse acute physiological effects. However, very little is known about how much variability exists in free-living daily sitting time within individuals (i.e., intra-individual). While we are unaware of studies that examined day to day variation in sitting time, there are studies that compared average sitting time between work days and leisure days[7] and between weekdays and weekend days.[8] Using self-reports of sitting based on a question of how much one "typically" sits on a "usual" weekday or "usual" weekend day, it was reported that among over 19,000 Australian women there is on average 0.5 to 1.0 h/day greater sitting on the weekdays compared to weekend days.[8] McCrady and Levine reported an average of 1.9 h/day longer sitting duration for work compared to leisure days using inclinometry (PAMS, see Ref. 9)[9] in 21 participants.[7] We would expect that within a week there would be much greater day to day variation within individuals than the difference between the average of 5 week (or work) days and 2 weekend (or leisure) days.

Recently, the technology to measure sedentary behavior objectively has emerged.[10,11] Objective measurement of sedentary behavior has been replacing questionnaires and diaries in some research settings.[12,13] However, the use of most hip-worn accelerometers to measure sedentary behavior rely on measuring lack of movement instead of posture, leading to misclassification of sitting time.[14,15] For example, Lyden et al.[15] demonstrated that the Actigraph GT3X was not accurate in measuring changes in sitting duration in a study aimed at reducing habitual sitting time. However, the activPAL (PAL Technologies, Glasgow, United Kingdom), can accurately determine time spent sitting.[14–18] The activPAL has been extensively tested in controlled lab conditions and has shown good reproducibility (Intraclass correlation coefficient (ICC) range from 0.79–0.99) and agreement (R^2=0.94) with direct observations of sitting,[14,16] indicating that it can accurately measure the behavior. For example, activPAL determined sitting duration was within 3% of the direct observation (i.e. 'gold standard') of free-living sitting duration while participants were primarily at work.[14] There is, however, limited information regarding the reliability of the measurement of free-living sedentary behavior (sitting time) on a daily basis using an accurate measurement tool like the activPAL. The degree of reliability refers to the repeatability or stability of a measure and takes into account the intra- and inter-individual variability. Reliability is an important statistical measurement property because it is the building block for accuracy.[19] It is also important to note that the level of reliability will

directly influence the correlation between two measures, as explained in the Attenuation Theory.[20]

Physical activity recommendations by the American College of Sports Medicine and the American Heart Association, and governmental agencies have focused on achievement of 150 min of moderate, or 75 min of vigorous, or a combination of the two physical activity levels per week in bouts of 10 min or more.[21] Thus far, the reliability of objectively measured recommended moderate-to-vigorous physical activity (MVPA) has been under examined with just one study[22] that has examined the recommended form of MVPA that is in sustained bouts of 10 min or more. Thus, the purpose of this study was to examine intra- and inter-individual variability, and secondly to determine if intra-individual variability was related to weekly averages of sitting duration and recommended moderate-vigorous physical activity (MVPA), and thirdly to determine the reliability of free-living sitting and recommended MVPA time objectively determined using the activPAL physical activity monitor.

ii. Methods

The participants in this study were part of a larger study which was approved by the Northwestern University and Pennington Biomedical Research Center Institutional Review Boards. All participants signed an informed consent prior to participation. Detailed information about the recruitment and procedures can be found elsewhere.[23] Thus, the essential parts to this study will be described here. Healthy women, aged 40–75 years were recruited for a study examining the relationships of lifestyle factors with mammographic breast density. Participants completed a questionnaire with demographic information, had their height and weight, as well as daily free-living sitting time and daily MVPA bouts measured. From the initially 100 recruited women 68 were included in this analysis as explained below.

The women were asked to wear the activPAL monitor for 7 consecutive days during waking hours, removing the monitor only when bathing or getting in contact with water. They were instructed to begin wearing the activity monitor immediately upon getting out of bed and to wear the monitor for the entire day, with the exception of bathing, and remove it before going to sleep. In addition, participants were asked to keep a log of the time they put on and took off the monitor each day. Non-wear time was determined with the participants' logs for "time on" and "time off" and the raw Excel files generated by the activPAL software. Data was also considered non-wear when there were obvious large blocks (>3hr) of continual sitting or lying with 0 or 1 counts in the accelerometer channel which was rare. Sitting duration was calculated by subtracting this non-wear time, assumed to be lying in bed, from total sedentary time.[23] To be included in this study, participants needed to have at least 10 hours of data for all 7 days (n=68). An MVPA bout was defined as 10 consecutive minutes over 100 steps/min using the activPAL. The 100 steps/min cutoff was chosen based on published work that has shown that a cadence greater or equal to 100 steps/min corresponds to energy expenditure consistent with MVPA.[24,25] Ten minutes is the minimum recommended bout duration of MVPA to achieve health benefits.[21] For more details see Craft et al.[23] The maximum and minimum daily sitting duration from the 7 days of

measurement was determined for the calculation of the range in sitting time within each individual. In addition, the data was divided into quartiles based on mean sitting time and mean MVPA cumulative bout time and the mean ranges were compared with an analysis of variance (ANOVA). Generalizability theory analysis was performed to determine the reliability of sitting time and MVPA bouts using the Generalized Analysis of Variance (GENOVA) software. The Generalizability theory has been previously used in the reliability analysis of physical activity measured by accelerometers and pedometers.[26,27] As explained in those previous studies, generalizability is an extension of intraclass reliability and ANOVA. Generalizability theory is divided into two parts. The G-study which can quantify the percent of variance associated with each facet and its interactions. For the G-study, participant (P) and day (D) were considered random facets in a fully crossed design (P D). The D-study provides a Generalizability coefficient (G), which can be interpreted identically to an intra-ICC value. With the D-Study, it is possible to determine the measurement model needed to achieve a recommended reliability estimate G≥0.80.

iii. Results

The participant's demographics are presented in Table 1. The mean daily sitting time and mean weekly MVPA cumulative bout time were 9.0±1.8 h/day and 154±140 min/week, respectively. The mean sitting time for each quartile was 6.7±0.8, 8.5±0.4, 9.7±0.3, and 11.3±1.1 h/day (Fig. 1a). The mean MVPA cumulative bout time by quartile was 12±16, 76±25, 167±27, 354±111 min/week (Fig. 1b). The individual mean sitting times, as well as the maximum and minimum values, are presented in Figure 1a. The participants' mean range for sitting time was 4.5±1.7 h/day, which was similar to the 4.5 h/day difference between the 1st and 4th quartiles of average sitting. This mean range within a week was not different between quartiles of individuals with low to high sitting time (4.9±1.9, 4.1±1.9, 5.1±1.5, 3.9±1.1 h/day, 1st–4th quartile) and between quartiles of people with different amounts of MVPA (4.2±1.8, 4.7±2.0, 4.6±1.5, 4.4±1.3 h/day, 1st–4th quartiles). Detailed information by each day of the week is shown in Supplementary Table S1. Average sitting duration was statistically significantly greater on weekdays than on weekend days (0.5±1.6 h/day, $p<0.01$). The intra-individual range of daily sitting time was very weakly related to the intra-individual range in daily wear time ($R^2=0.09$) indicating that intra-individual range in sitting was not just due to how long the participants wore the monitor on those days.

In the sitting time analysis, the G-study results demonstrated that the largest source of variance in the model was the participants (P), accounting for 51% of the variance. This indicates large inter-individual differences in average time spent sitting across the week. Days (D) accounted for only 1% of the variance, indicating that daily group means are relatively stable. The PxD interaction, which includes residual error and accounts for sources of error not considered in the G-study was responsible for 48% of variability, reflecting the different relative standings of participants across days related to the amount of time spent sitting. The D-study results can be seen in Figure 2a. It is possible to observe a curvilinear relationship between the number of wear days and the G-coefficient. Specifically, as the number of wear days increases the increase in the G-coefficient is diminished. A total of 4 days were sufficient to achieve a reliable estimate G = 0.80, 9 days would be necessary for

an estimated coefficient greater than 0.9, and an estimated G = 0.97 would be achieved with 30 days of measurement.

In the MVPA analysis, the G-study results demonstrated that participants (P) account for 37% of variance in the model and did not account for the largest source of variance. Days (D) accounted for less than 1%, indicating that daily group means are relatively stable. The PxD interaction was responsible for 62% of variability, reflecting the different relative standings of participants across days related to the amount of time spent in MVPA cumulative bouts. The D-study results can be seen in Figure 2b. As can be seen, the curve for MVPA bouts is much lower than the curve for sitting time. A total of 7 days were necessary to achieve a reliable estimate G = 0.80, 21 days would be necessary for an estimated coefficient greater than 0.9, and an estimated G = 0.95 would be achieved with 30 days of measurement.

iv. Discussion

We report, for the first time, the intra-individual variability in objectively determined daily sitting time. On average, participants had a range of 4.5 h/day sitting time within 1 week. Interestingly, the magnitude of this mean range was consistent regardless of how much the individuals sat over the whole week or time spent in recommended MVPA. The difference between the mean of the lowest and the highest quartiles of objectively determined sitting was also 4.5 h/day. Therefore, on 1 day of the week an individual could be classified in the high sitter quartile (>11 h/day) and on another day within the same week, that same individual could be classified in the low sitter quartile (<7h/day). In addition, generalizability theory analysis indicated that 4 days of assessing objectively determined sitting posture with the activPAL is sufficient to achieve a desirable level of reliability (G = 0.80). This information should be used to guide data collection methods when objectively measuring sedentary behavior in adults.

These findings regarding the intra-individual range in daily sitting time may be of physiological importance because of the acute effects of altering the balance between sedentary time and LIPA. Although the dose response effects of acute sitting have not been well investigated to date, preliminary evidence from experimental trials indicate that altering the balance between muscle inactivity (sitting in humans) and LIPA, within 1 day,[1–4] and 4 days [28] can have potent and adverse physiological effects. We reported that there is a marked loss of lipoprotein lipase enzyme activity within 6–18 hours of muscular inactivity[3,4] and that low-intensity standing and ambulation is an effective countermeasure.[3]

The quartiles of sitting time ranged from 6.7 to 11.3 h/day in the lowest to highest sitting groups. The difference between the 1st and 4th quartiles is consistent with published SD values from population and large sample studies, albeit using less accurate measures of sedentary time.[10,29] For example, NHANES analysis of sedentary time (using the Actigraph 7164) in the US population reported that the standard deviation (SEM × square root of n) among women aged 40–69 years is 1.7–1.8 h/day.[10] Using the SD and assuming a normal distribution, there would be a 4.5–5.0 h/day difference between the top (87.5th percentile) and bottom (12.5th percentile) quartile in close agreement with the results of this study.

While we are unaware of any studies in adults examining the reliability of objectively determined daily free-living sitting behavior, a number of studies have used hip worn accelerometry (e.g., Actigraph) to estimate sedentary time over 7 days of measurement with 3–5 days being considered enough days for participants to be included in the analysis.[13] However, the reliability of daily sedentary behavior has not been extensively studied in adults and the 3–5 days requirement was not empirically derived. The reliability of sedentary behavior (not necessarily sitting), defined by <100 cts/min, has been estimated for older adults.[30] In that study, 5 days were required to reliably estimate sedentary behavior (ICC≥0.8), which is close to the number of days found in this study. Similarly, in a recent study of 143 adults using a hip worn Actigraph accelerometer, Sirard et al.[31] reported an ICC of 0.84 for free-living sedentary behavior from week to week. While the reliability results from previous studies were similar to the ones found in this study, to our knowledge this is the first reliability study in adults that uses a device that can accurately measure the sitting behavior using inclinometry.

The reliability estimates of daily physical activity have been the topic of many studies, but few in the adult population. A number of studies have focused on the reliability estimates of steps/day while only a few have examined the reliability of total non-bout and bout MVPA in adults measured by hip worn accelerometry.[31,32] One of the earlier studies[32] found that 3 days for men and 4 days for women were enough to achieve an ICC > 0.8. Only 2 days of total (combining non-bout and bout) MVPA was needed in older adults to achieve an ICC ≥ 0.80 and Sirard et al.[31] reported an ICC of 0.90 between two weeks of measurement in adults. Sirard et al.[31] also indicated that only 2–3 days are needed to achieve an ICC > 0.8. These results seem in conflict with the 7 days needed for the time spent in recommended MVPA to achieve a G=0.8 reported in this study. However, this present study is examining the form of MVPA recommended by the U.S. Dept. of Health and Human Services[21] and many other governments and other organizations which is to be performed in bouts of at least 10 minutes and thus is a unique form of MVPA and apparently more variable. Indeed, in the only study that examined the reliability of MVPA bouts (recommended MVPA) in adults using hip worn accelerometry,[22] it was estimated at different time points and for different samples that a minimum of 13 and as many as 35 days were necessary to achieve an ICC value > 0.8, which was much greater than the 2–4 days needed for ICC ≥ 0.8 in total cumulative MVPA (combining non-bout and bout).

The importance of reliable measurement tools and reliable measurement of behaviors in the sports medicine area have been recognized by other researchers.[32] However, the correlation attenuation effect caused by poor reliability[19,20] has been under studied and undetermined in the physical activity and sedentary behavior areas. Poor reliability is partially responsible for the poor correlations found among different measures of physical activity and sedentary behavior (i.e., questionnaires, accelerometry, pedometers).[19,20] Researchers should be more attentive to this issue and should not only report reliability measures but should also use the reliability coefficients to determine the minimum number of days of valid data to allow a participant to be included in the analysis.

Although carefully conducted, this study is not free of limitations. Only women (52.4±8.4 years) were included in the analysis. Additional studies to determine the reliability of daily

sitting time and MVPA bouts in other populations are necessary. As demonstrated in the previous publication, the women that volunteered to participate in this study were fairly active with regards to average MVPA[23] and the results for MVPA found in this study might not be generalizable to other samples. A limitation of using stepping rate to assess MVPA is that we would not be able to measure some forms of MVPA such as swimming. However, this method should do well at measuring walking which is considered the most common form of leisure time physical activity in the U.S.[33] The women in this study wore the monitor for one week. Thus, it was not possible to conduct analysis to determine if there were differences in reliability estimates over months or different seasons. The interaction term PxD, which accounts for the sources of error not considered in the G-study, was high for both sitting and bouted MVPA, indicating that other unknown factors may play a role in the variability of sedentary behavior and bouted MVPA. It is important to note that reliable measurement is the first step into obtaining valid data, however obtaining reliable measures does not guarantee that the measurement represents habitual behavior.[34] Studies measuring these behaviors for long durations are necessary to determine habitual values[26].

v. Conclusion

The findings of this study demonstrate that there is considerable variation in daily sitting both within and between individuals. Within one week of monitoring, there was a 4.5 hour/day range of sitting within individuals indicating that the average “sitter” can have daily sitting durations that are as high as the high sitters (highest quartile) or as low as the low sitters (lowest quartile). Furthermore, to obtain a desirable reliability level (G=0.80), 4 and 7 days of monitoring were necessary for free-living sitting time and time spent in recommended sustained MVPA bouts, respectively.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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viii. References

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vi. Practical Implications

- There is about a 4 hour difference in the average daily sitting duration between high and low sitters based on the top and bottom quartiles.
- Regardless of how much one sits on average or how much recommended MVPA one performs on average, there is about a 4 hour difference between the days with the highest and lowest sitting duration within one week. Therefore, one could be classified as a high sitter or low sitter based on the individual day that sitting is measured.
- In order to get a reliable measurement of daily sitting time with an inclinometer, at least 4 measurement days are necessary.

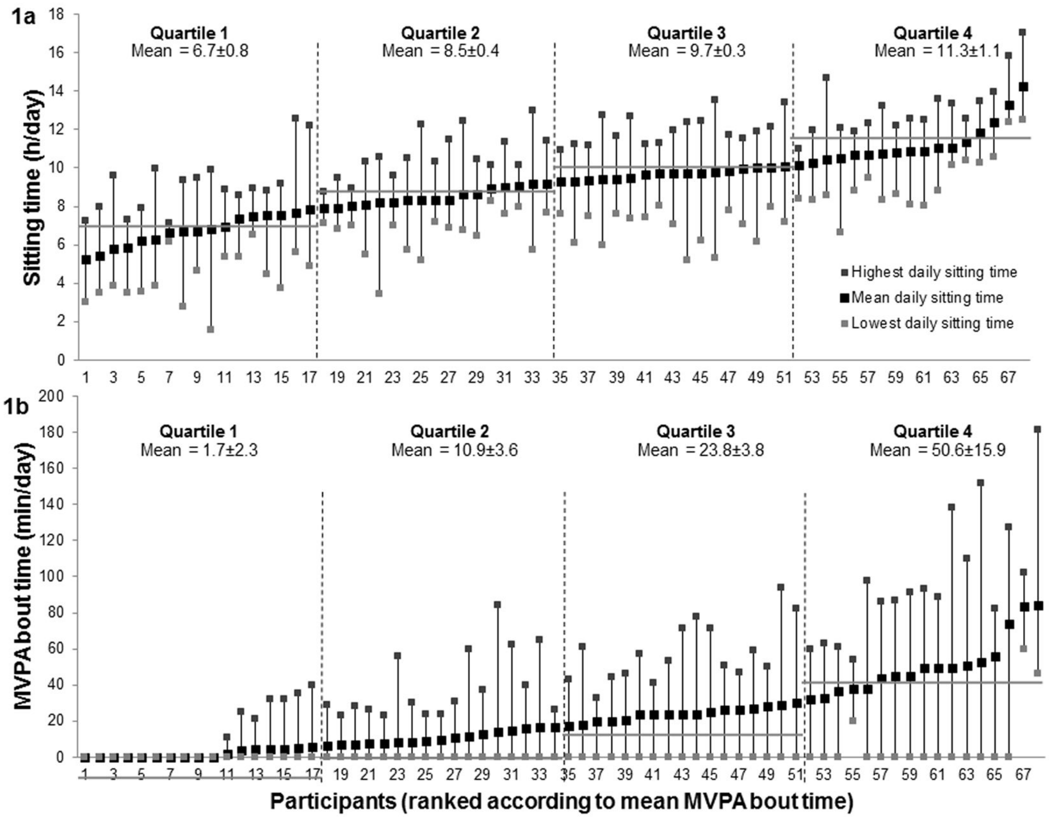

Figure 1.

Individuals' distribution of sitting time and MVPA bout time with quartile distribution.

Note. Vertical broken lines indicate quartile separation and horizontal lines indentifies mean time for participants in the quartile.

1a – Sitting time

1b – MVPA bout time

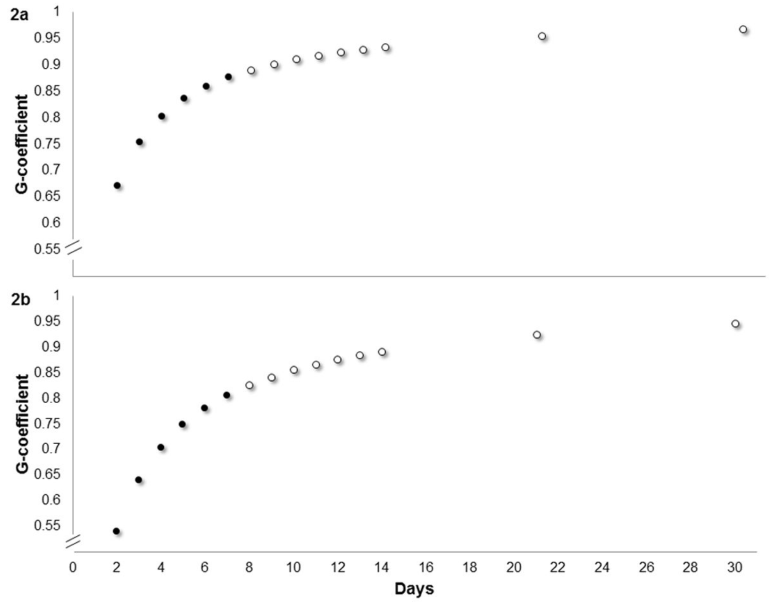

Figure 2.
Reliability coefficients for different number of days of measurement of sitting time and MVPA bout time by the activPAL monitor.

Note. Solid circles indicate measured values, open circles indicate estimated values

2a – Sitting time

2b – MVPA bout time

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Table 1

Participant's demographics (n=68)

Variables	**Mean±SD or %**
Age (years)	52.4±8.4
Body Mass Index (kg/m^2)	26.4±6.0
Race	
Caucasian	88.2%
African American	10.3%
Other	1.5%
Menopausal Status	
Postmenopausal	51%
Premenopausal	49%
Education	
High School graduate	7.4%
Some college	7.4%
College graduate	38.2%
Graduate School	47.1%