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**Research article**

# Towards Uniform Accelerometry Analysis: A Standardization Methodology to Minimize Measurement Bias Due to Systematic Accelerometer Wear-Time Variation

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**Abstract**
Accelerometers are predominantly used to objectively measure the entire range of activity intensities ─ sedentary behaviour (SED), light physical activity (LPA) and moderate to vigorous physical activity (MVPA). However, studies consistently report results without accounting for systematic accelerometer wear-time variation (within and between participants), jeopardizing the validity of these results. This study describes the development of a standardization methodology to understand and minimize measurement bias due to wear-time variation. Accelerometry is generally conducted over seven consecutive days, with participants' data being commonly considered 'valid' only if wear-time is at least 10 hours/day. However, even within 'valid' data, there could be systematic wear-time variation. To explore this variation, accelerometer data of Smart Cities, Healthy Kids study (www.smartcitieshealthykids.com) were analyzed descriptively and with repeated measures multivariate analysis of variance (MANOVA). Subsequently, a standardization method was developed, where case-specific observed wear-time is controlled to an analyst specified time period. Next, case-specific accelerometer data are interpolated to this controlled wear-time to produce standardized variables. To understand discrepancies owing to wear-time variation, all analyses were conducted pre- and post-standardization. Descriptive analyses revealed systematic wear-time variation, both between and within participants. Pre- and post-standardized descriptive analyses of SED, LPA and MVPA revealed a persistent and often significant trend of wear-time's influence on activity. SED was consistently higher on weekdays before standardization; however, this trend was reversed post-standardization. Even though MVPA was significantly higher on weekdays both pre- and post-standardization, the magnitude of this difference decreased post-standardization. Multivariable analyses with standardized SED, LPA and MVPA as outcome variables yielded more stable results with narrower confidence intervals and smaller standard errors. Standardization of accelerometer data is effective in not only minimizing measurement bias due to systematic wear-time variation, but also to provide a uniform platform to compare results within and between populations and studies.

**Key words:** Accelerometry, wear-time variation, data standardization.

## Introduction

Different types of accelerometers are increasingly being used in interdisciplinary research to objectively measure activity patterns in populations (Feinglass et al., 2011; Kristensen et al., 2010; Laguna et al., 2013; Prince et al., 2011; Straker et al., 2012;). Activity includes a wide range of physical activity and sedentary behaviours which can be measured by accelerometers. For the purpose of this study, physical activity is defined as any body movement produced by skeletal muscles that requires energy expenditure (Caspersen et al., 1985). Similarly, sedentary behaviour is defined as lack of body movement during waking time that does not increase energy expenditure substantially above the resting level (Pate et al., 2008; Sedentary Behaviour Research Network, 2012).

The popularity of accelerometers is based on their documented superiority over self-reported measures (Celis-Morales et al., 2012; Prince et al., 2008) and their ability to provide a detailed picture of frequency and duration of activity intensities ─ sedentary behaviour (SED), light physical activity (LPA) and moderate to vigorous physical activity (MVPA) (Baquet et al., 2007). A growing reliance on accelerometers to study patterns of activity within and between populations makes the measurement and analysis protocol of accelerometer measures a key methodological issue.

In population health studies, accelerometers are typically used to collect data during waking hours from participants over a period of 7 consecutive days ─ 5 weekdays and 2 weekend days (Colley et al., 2011; Esliger et al., 2012; Feinglass et al., 2011; Kristensen et al., 2010; Tudor-Locke et al., 2011). Widely accepted data reduction standards (Colley et al., 2010) deem that participants are required to wear accelerometers (wear-time) for at least 10 hours on a given day to capture the entire range of activity, and such a day is termed a valid day.

Analyses are conducted using data only from the valid days (Colley et al., 2011; Esliger et al., 2012), however, even within this valid data, there is a chance for systematic variation in daily wear-time, both within (on different days of accelerometer use) and between participants. This is because, even though participants are asked to wear accelerometers from the time they wake up in the morning till the time they go to bed at night, every participant would wear or remove the accelerometer at her/his discretion, thus potentially introducing a random or non-random bias to activity measurement.

A random (but highly imprecise) bias would result if accelerometers are removed during waking hours (non-wear-time) by participants without regard to the type of activity that subsequently goes unmeasured. A non-random bias would result if accelerometers are removed during waking hours by participants consistently before engaging in a certain type of activity. In other words,

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activity measured overall is consistently different from the real activity engaged by participants. Furthermore, in large population health studies, as variation in wear-time increases, the chance of final estimates of activity being distorted increases as wear-time is directly related to the amount of activity measurement.

Specific to non-wear-time, Tudor-Locke et al (2011), using accelerometer data from the 2005-2006 National Health and Nutritional Examination Survey, concluded that non-wear-time appears to distort population estimates of all accelerometer measured activity, especially estimates of SED. However, distinct from non-wear-time, the purpose of this particular study is to explicitly address the impact of systematic variation of wear-time on estimates of activity. To our knowledge, apart from statistically controlling for wear-time in multivariable analyses by including it as an independent variable (Bond et al., 2012), most studies so far have not taken into account wear-time discrepancies and their impact, before performing final analyses.

Two studies that have explored wear-time variation arrived at inconclusive results (Catellier et al., 2005; Chen et al., 2009). For example, Catellier and colleagues (2005) utilized sophisticated imputation methods in tackling wear-time irregularities with an assumption that the data (activity) were missing at random, or completely missing at random. However, at the same time, the authors acknowledged that there is no objective way of determining whether the data are missing at random, completely missing at random, or not missing at random.

To preserve the expected objectivity of accelerometry and to avoid complicated statistical techniques that rely on many assumptions, a method of standardization of measured activity controlling for wear-time is essential. This approach would not only minimize measurement bias due to systematic wear-time variation, but would also create a uniform platform to compare estimates of activity obtained from all types of accelerometers, both within and between populations.

## Methods

To advance this argument, data from Smart Cities Healthy Kids study (www.smartcitieshealthykids.com) has been used. Smart Cities, Healthy Kids which is set in Saskatoon, Saskatchewan, Canada, is an ongoing population health intervention study that investigates the influence of neighbourhood built environment on activity patterns in children aged 10-14 years. From the original sample 1610 children, objective activity data were collected using Actical accelerometers (Mini Mitter Co., Inc., Bend, OR, USA) from a subgroup of 455 children. Prior to deploying the accelerometers, a questionnaire was administered to children to capture their demographic data. Ethics approval from the University of Saskatchewan's research ethics board and both Catholic and public schools boards was obtained before accelerometers were deployed through schools from April to June in 2010. Participants were visited at their respective schools and were asked to wear the devices on their right hip using an elastic belt, every day for 7 consecutive days. They were advised to remove the accelerometers during night time sleep and during any water-based activities.

Accelerometers measured movement in 15 second epochs in order to capture the sporadic nature of children's physical activity (Bailey et al., 1995). The raw data were analyzed using custom software, KineSoft version 3.3.63 (KineSoft, Loughborough, UK) to produce a series of activity intensities measured in minutes, representing the complete range of daily activity, i.e., SED, LPA and MVPA. The cut-points used to derive these activity intensities (SED: <100 counts/minute; LPA: 100 to <1500 counts/minute; MVPA: ≥1500 counts/minute) were selected based on evolving evidence (Evenson et al., 2008; Heil et al., 2006; Puyau et al., 2004; Wong et al., 2011).

Moreover, the accelerometers and the cut-points used in our study are the same as those used in the 2007-2009 Canadian Health Measures Survey (Colley et al., 2011), whose accelerometry results depicted activity patterns in a nationally representative sample of children in Canada. Furthermore, using the accelerometer sample of the 2007-2009 Canadian Health Measures Survey, operational definitions and data reduction techniques were developed by Colley et al (2010). These definitions and techniques were adopted to generate valid data for our study.

A valid day was defined as a day of accelerometry with 10 or more hours of wear-time (Troiano et al., 2008). Daily wear-time was estimated by subtracting non-wear-time from 24 hours of that particular day. It was determined that non-wear-time would be a period of at least 60 consecutive minutes of zero counts, including up to 2 minutes of counts between 0 and 100 (Colley et al., 2010). The final sample consisted of data from participants with at least 4 valid days including at least 1 valid weekend day, i.e., the valid sample. The valid sample comprised of 331 children (Age groups: 10 years [n = 70]; 11 years [n = 91]; 12 years [n = 85]; 13 years [n = 64]; 14 years [n = 21]) including 166 boys and 165 girls.

### Statistical analysis

All analyses were conducted using the valid sample. First, using valid days' data from the complete valid sample (N=331 participants with 4 or more valid days), between participant wear-time variation was examined. Next, to assess systematic wear-time variation within participants over the entire 7 day accelerometry period, repeated measures multivariate analysis of variance (MANOVA) and pairwise comparisons between each day of accelerometry were conducted using a sub-sample from the complete valid sample. All participants in this sub-sample (n = 130) had valid data on all 7 days of accelerometry.

Finally, valid days' data from the complete valid sample were analyzed to understand discrepancies in final results owing to wear-time variation. In this final round, all analyses (descriptive and multivariable) were conducted twice: first with the pre-standardized outcome variables, and then the same analyses were repeated using standardized outcome variables. The outcome variables in all final analyses were mean SED, LPA and MVPA, either pre-standardized or post-standardized. Data were analyzed using SPSS (version 20.0), and significance was determined at $p < 0.05$.

## Standardization

Within the valid sample, for each participant, case specific sum of 'valid days' ($\sum VD$) was multiplied by an analyst defined time period (10 hours in this study) to determine case specific controlled wear-time ($wt_{CON}$).

$$wt_{CON} = \sum VD \times 10 \text{ hours} \qquad \text{Equation A}$$

Subsequently, the observed or unstandardized total valid activity intensities in minutes ($Act_{USTD}$) i.e., SED, LPA or MVPA of each participant were interpolated to this case specific controlled wear-time to calculate case specific standardized total valid activity intensities in minutes ($Act_{STD}$).

$$Act_{STD} = \frac{(\sum VD \times 10) \times Act_{USTD}}{wt_{UCON}} \text{ minutes} \qquad \text{Equation B}$$

*Where, $wt_{UCON}$ is the observed or uncontrolled valid wear-time.*

Finally, the standardized total valid activity intensities of each participant were divided by case specific sum of 'valid days' to derive case specific standardized *mean* activity intensities in minutes (Mean $Act_{STD}$) i.e., ─ standardized mean SED, LPA or MVPA.

$$\text{Mean } Act_{STD} = \frac{\frac{(\sum VD \times 10) \times Act_{USTD}}{wt_{UCON}}}{\sum VD} \text{ minutes} \qquad \text{Equation C}$$

A standardization scenario ─ Assume that a participant has 4 valid days, and during these 4 valid days, assume that this participant actually accumulated 48 hours of wear-time (uncontrolled wear-time). Suppose during these 48 hours of total wear-time, this participant accumulated total valid MVPA of 400 minutes (unstandardized MVPA), then the standardized mean MVPA will be calculated using this procedure ─ First, the 4 valid days will be multiplied by 10 hours to calculate the controlled wear-time of 40 hours (equation A). Next, the 400 minutes of total unstandardized MVPA will be multiplied by 40 hours of controlled wear-time and this amount will be divided by 48 hours of uncontrolled wear-time to arrive at total standardized MVPA of 333.33 minutes (equation B).

Finally, this total standardized MVPA will be divided by the 4 valid days to calculate the standardized mean MVPA of 83.33 minutes for this participant (equation C). This standardization procedure will be conducted for each participant in the study to calculate the standardized mean SED, LPA and MVPA of all participants.

# Results

Figure 1 descriptively outlines the variation in mean daily wear-time between participants across the total valid sample. After descriptively exploring variation of wear-time between participants, repeated measures MANOVA using both the univariate and multivariable approaches showed significant change in wear-time during the 7 day period of accelerometry. The within-subject effect tested with the Greenhouse-Geisser adjustment (Greenhouse and Geisser, 1959) yielded highly significant estimates ($F_{GG\,(5.27,\,679.8)} = 35.63$, $p < 0.001$) and 21% of the wear-time variation was explained by the 7 day period of accelerometry i.e., time effect.

The within participant wear-time variation was further explored by pairwise comparisons between each day of the week (Table 1). This analysis showed the systematic nature of wear-time variation over one week of accelerometry. Among the weekdays, participants consistently accumulated lower wear-time on Mondays and higher wear-time on Fridays in comparison with all other weekdays. Another consistent finding was the accumulation of lower wear-time on weekend days in comparison with all other days of the week.

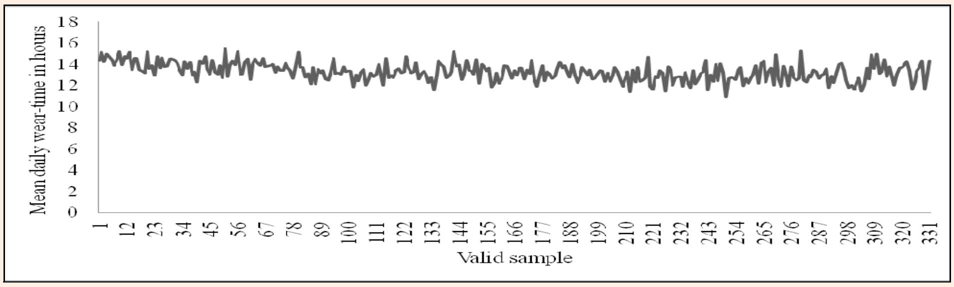


**Figure 1. Descriptive picture of mean daily wear-time differences between all participants in the valid sample.**

**Table 1. Pairwise comparisons depicting wear-time differences in minutes between each day of accelerometry.**

| Mean Differences † | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|---|---|---|---|---|---|---|---|
| **Monday** | **.000** | | | | | | |
| **Tuesday** | 22.22* | **.000** | | | | | |
| **Wednesday** | 23.30* | 1.175 | **.000** | | | | |
| **Thursday** | 27.60* | 5.479 | 4.303 | **.000** | | | |
| **Friday** | 70.28** | 48.16** | 46.99** | 42.68** | **.000** | | |
| **Saturday** | 14.16 | -7.962 | -9.137 | -13.44 | -56.12** | **.000** | |
| **Sunday** | -59.12** | -81.12** | -82.41** | -86.72** | -129.4* | -73.28** | **.000** |

† Each value presented in the table is a result of subtraction of wear-time between 2 days of accelerometry (days in columns subtracted from days in rows). ** $p < 0.001$; * $p < 0.01$.


**Figure 2. Paired t-tests showing differences between mean daily wear-time on weekdays and weekend days.** ***$p < 0.001$

After observing the systematic variation in wear-time, the pattern of higher wear-time during weekdays was further explored. Figure 2 depicts a highly consistent and statistically significant pattern of higher wear-time during weekdays in comparison with weekend days across all age groups as tested by paired t-tests — [$t_{(330)}$ = 11.74, $p < 0.001$]; 10 years [$t_{(69)}$ = 3.82, $p < 0.001$]; 11 years [$t_{(90)}$ = 6.90, $p < 0.001$]; 12 years [$t_{(84)}$ = 6.35, $p < 0.001$]; 13 years[$t_{(63)}$ = 4.76, $p < 0.001$]; 14 years [$t_{(20)}$ = 4.38, $p < 0.001$].This observation provided the rationale for testing measurement of activity accumulation pre- and post-standardization between weekdays and weekend days using paired t-tests.

Figure 3a shows the comparison of pre-standardized mean SED during weekdays and weekend days. Consistent with the pattern depicted in figure 2, weekdays have higher values than weekend days across all age groups, with statistically significant differences observed in the total sample [$t_{(330)}$ = 3.41, $p < 0.001$] and in the age groups of 12 years [$t_{(84)}$ = 2.16, $p < 0.05$], 13 years [$t_{(63)}$ = 2.0, $p < 0.05$] and 14 years [$t_{(20)}$ = 2.12, $p < 0.05$]. When the same analysis was repeated post-standardization (Figure 3b), an opposite pattern was observed — higher values of SED were observed on weekend days across all age groups, with statistically significant differences observed in the total sample [$t_{(330)}$ = 5.68, $p < 0.001$] and in the age groups of 10 years [$t_{(69)}$ = 2.28, $p < 0.05$], 11 years [$t_{(90)}$ = 3.78, $p < 0.001$] and 12 years [$t_{(84)}$ = 3.08, $p < 0.05$].

Figures 4a and 4b depict the pre- and post-standardized mean MVPA during weekdays and weekend days. Weekday values of MVPA were significantly higher compared to weekend values across all age groups — [$t_{(330)}$ = 16, $p < 0.001$]; 10 years [ $t_{(69)}$ = 6.64, $p < 0.001$]; 11 years [ $t_{(90)}$ = 10.36, $p < 0.001$]; 12 years [ $t_{(84)}$ = 9.63, $p < 0.001$ ]; 13 years[ $t_{(63)}$ = 4.29, $p < 0.001$]; 14 years [ $t_{(20)}$ = 5.0, $p < 0.001$].

However, unlike the post-standardized SED pattern, weekday MVPA remained significantly higher across all age groups even after standardizing the data —

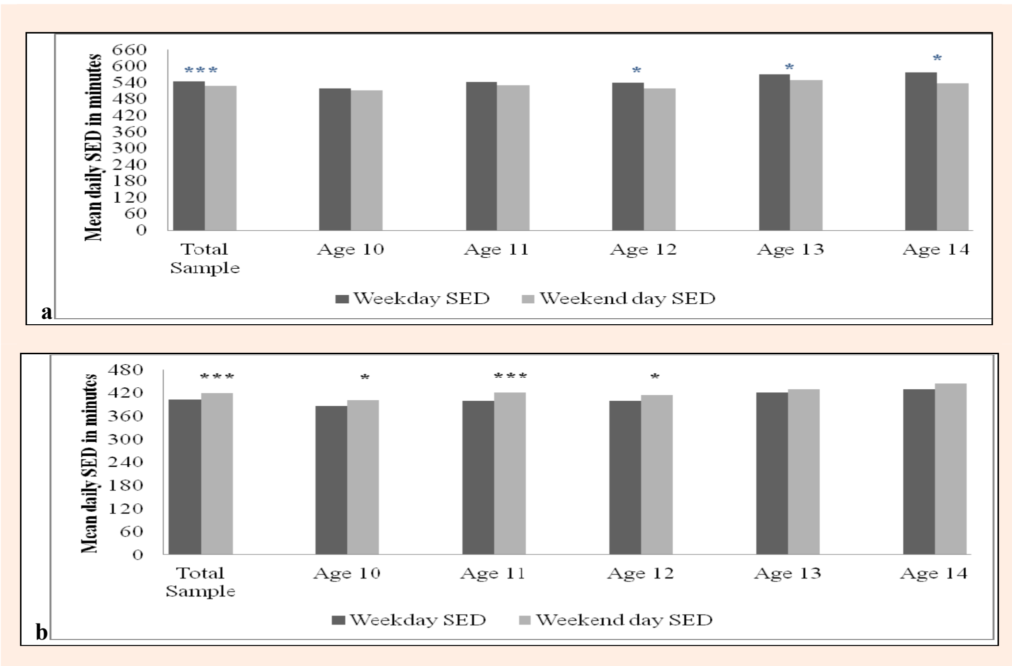


**Figure 3. Paired t-tests showing the influence of wear-time on weekday and weekend SED estimates. 3a: Paired t-tests showing differences between mean daily Pre-standardized SED on weekdays and weekend days. 3b: Paired t-tests showing differences between mean daily post-standardized SED on weekdays and weekend days.** *$p < 0.05$; ***$p < 0.001$

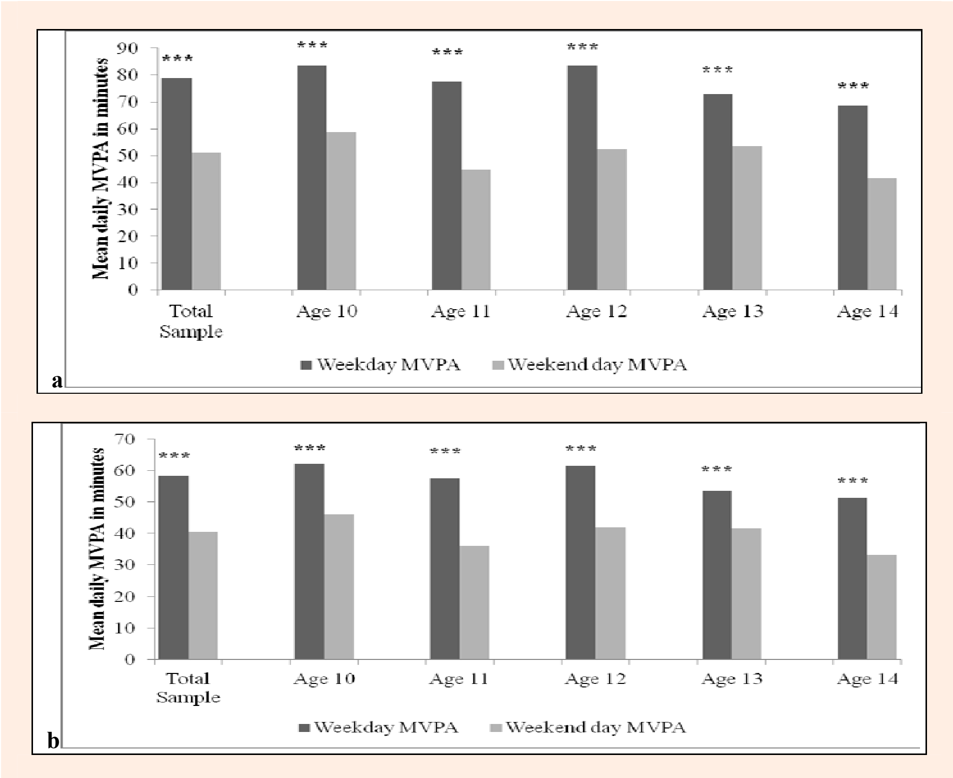


**Figure 4. Paired t-tests showing the influence of wear-time on weekday and weekend MVPA estimates. 4a: Paired t-tests showing differences between mean daily Pre-standardized MVPA on weekdays and weekend days. 4b: Paired t-tests showing differences between mean daily post-standardized MVPA on weekdays and weekend days.** ***p < 0.001

total sample [$t_{(330)} = 5.69$, $p < 0.001$]; 10 years [ $t_{(69)} = 5.43$, $p < 0.001$]; 11 years [ $t_{(90)} = 8.39$, $p < 0.001$]; 12 years [ $t_{(84)} = 7.95$]; 13 years[ $t_{(63)} = 3.65$, $p < 0.001$]; 14 years [ $t_{(20)} = 3.8$, $p < 0.001$]. With LPA, descriptive analysis comparing weekday and weekend values did not show statistically significant differences, both pre- and post-standardization (data not shown). After descriptive analyses, with SED, LPA and MVPA as the outcome variables, bivariate analyses were conducted to identify significant demographic factors — age, sex, ethnicity (data not shown). Thereafter, these significant independent factors were used to conduct multivariable analyses — first with pre-standardized outcome variables (Table 2), and then with post-standardized outcome variables (Table 3). For all pre-standardized analyses, to statistically adjust for wear-time bias, mean daily wear-time was used as a covariate in the models. Even after controlling for wear-time in pre-standardized models, the results obtained in the post-standardized models were superior — for all outcomes and for each independent variable included in the

**Table 2. Multivariable linear regression models for accelerometer outcomes before data standardization; C.I: confidence interval. Values that differ from post-standardized models are in bold font.**

| Outcome variable: sedentary behaviour | | | | | |
|---|---|---|---|---|---|
| | | | | 95.0% C.I | |
| **Covariates** | **Std. Error** | **Estimate** | ***p*** **-value** | **Lower Bound** | **Upper Bound** |
| **Gender** | **6.137** | .082 | .086 | **-1.504** | **22.64** |
| **Age** | **2.550** | .233 | .000 | **7.590** | **17.62** |
| **Aboriginal** | **7.665** | .112 | .017 | **3.230** | **33.39** |
| **Wear time** | 3.605 | .466 | .000 | 28.33 | 42.52 |
| **Outcome variable: Light physical activity** | | | | | |
| | | | | 95.0% C.I | |
| **Covariates** | **Std. Error** | **Estimate** | ***p*** **-value** | **Lower Bound** | **Upper Bound** |
| **Gender** | **-0.056** | -1.141 | .255 | **-11.90** | **3.163** |
| **Age** | **-0.318** | -6.496 | .000 | **-13.52** | **-7.234** |
| **Aboriginal** | **-0.151** | -3.028 | .003 | **-24.37** | **-5.174** |
| **Wear time** | .316 | 6.338 | .000 | .530 | 1.007 |
| **Outcome variable: Moderate to vigorous physical activity** | | | | | |
| | | | | 95.0% C.I | |
| **Covariates** | **Std. Error** | **Estimate** | ***p*** **-value** | **Lower Bound** | **Upper Bound** |
| **Gender** | **-.132** | -2.438 | .015 | **-15.15** | **-1.619** |
| **Age** | **-.091** | -1.694 | .091 | **-5.233** | **.390** |
| **Aboriginal** | **-.106** | -1.980 | .049 | **-16.96** | **-.055** |
| **Wear time** | .133 | 2.451 | .015 | .978 | 8.928 |

**Table 3.** Multivariable linear regression models for accelerometer outcomes after data standardization; C.I: confidence interval. Values that differ from pre-standardized models are in bold font.

| Outcome variable: sedentary behaviour | | | | | |
|---|---|---|---|---|---|
| | | | | 95.0% C.I | |
| Covariates | Std. Error | Estimate | *p* -value | Lower Bound | Upper Bound |
| Gender | **4.591** | **.102** | .053 | **-.120** | **17.95** |
| Age | **1.922** | .264 | .000 | **5.885** | **13.45** |
| Aboriginal | **5.777** | .122 | .020 | **2.088** | **24.82** |
| Wear-time has been controlled by standardization of sedentary behaviour | | | | | |
| **Outcome variable: Light physical activity** | | | | | |
| | | | | 95.0% C.I | |
| Covariates | Std. Error | Estimate | *p* -value | Lower Bound | Upper Bound |
| Gender | **-.049** | -.958 | .339 | **-8.031** | **2.769** |
| Age | **-.349** | -6.787 | .000 | **-10.06** | **-5.538** |
| Aboriginal | **-.106** | -2.059 | .040 | **-13.91** | **-0.316** |
| Wear-time has been controlled by standardization of light physical activity | | | | | |
| **Outcome variable: Moderate to vigorous physical activity** | | | | | |
| | | | | 95.0% C.I | |
| Covariates | Std. Error | Estimate | *p* -value | Lower Bound | Upper Bound |
| Gender | **-.133** | -2.456 | .015 | **-11.31** | **-1.249** |
| Age | **-.095** | -1.745 | .082 | **-3.975** | **.238** |
| Aboriginal | **-.107** | -1.970 | .050 | **-12.67** | **-.008** |
| Wear-time has been controlled by standardization of moderate to vigorous physical activity | | | | | |

models, the results depicted narrower confidence intervals, smaller standard errors, and sometimes higher beta coefficients, particularly for SED outcome variable (Table 3).

## Discussion

The purpose of this study is to develop a standardization methodology to understand and minimize the influence of wear-time variation on activity measurement. To our knowledge, studies to date, typically do not report the exploration of wear-time variation, and/or the influence of this variation on analyses and conclusions. In this study, a number of analyses were conducted to determine that wear-time could vary between participants (Figure 1) and within participants (Table 1).

Furthermore, a characteristic wear-time variation pattern over the entire 7 day accelerometry period was observed (Table 1). On weekdays, starting with low wear-time on Monday, there was a gradual increase as the week progressed, with wear-time peaking on Friday. However, a notable drop was observed over the weekend, with participants accumulating lower wear-time on Saturday and Sunday.

It would be interesting to see if similar patterns exist in other accelerometry data sets or in future studies conducting accelerometry. More importantly, it is essential to explore wear-time variation in detail to identify unique patterns so that these patterns are taken into account in final analyses. For example, in this study, the significant differences between weekday and weekend day wear-time (Table 1 and Figure 2) determined the type of descriptive analyses that were conducted for accelerometer outcomes before and after standardization.

These descriptive analyses compared pre- and post-standardized weekday and weekend measurement of MVPA, SED and LPA. Weekday MVPA was significantly higher than weekend day MVPA across all age groups, both before and after standardization of data (figures 4a, 4b), confirming prevailing evidence that children are more active on weekdays (Rowlands et al., 2008; Treuth et al., 2007). However, after standardization, the magnitude of the weekday vs. weekend MVPA difference reduced considerably.

Tudor-Locke et al (2011) in their assessment of impact of non-wear-time on accelerometer outputs speculated that not wearing accelerometers during waking hours affects SED more adversely than other intensities. This speculation is confirmed in this study by the evidence generated in the pre- and post-standardized descriptive analyses of SED. Wear-time which was significantly lower during the weekend days (table 1 and figure 2) was obviously a result of participants removing their accelerometers for longer periods during weekend waking hours. This, as expected from previous reported observations (Tudor-Locke et al., 2011), resulted in lower 'non-standardized' estimates of SED on weekends (figure 3a). However, after data were standardized by controlling for wear-time variation, weekend SED estimates turned out to be higher than weekday estimates (Figure 3b). This finding is important as it means that not accounting for systematic wear-time variation across weekdays and weekend days could lead to opposite conclusions.

As shown here, when conducting accelerometry over a period of 7 days in population health studies, wear-time variation should be expected, both within and between participants. However, it is difficult to expect or speculate the magnitude of wear-time's impact on the estimation of activity intensities which could vary between different groupings or even settings (weekday vs. weekend, boys vs. girls, etc…).

This is where data standardization plays a role in generating evidence to not only confirm wear-time's influence on estimation of activity intensities, but also to understand the magnitude of this influence. In doing this, data standardization reduces the measurement bias due to wear-time variation and creates a uniform platform to not only derive activity intensities, but also to compare them across different groups.

Beyond descriptive analyses, standardization of accelerometer data could aid in building robust multivariable models. Studies so far have accounted for wear-time in multivariable analyses by including wear-time as an independent variable (Bond et al., 2012). This commonly used method was tested by comparing multivariable analyses conducted with all three activity intensities as outcome variables, both before and after data standardization (Tables 2 and 3). For all three outcome variables (mean SED, LPA and MVPA), post-standardized multivariable analyses yielded more stable results.

With the ever increasing focus on active living, dependency on accelerometers or similar objective activity recorders will inevitably increase. To curtail inaccurate conclusions due to wear-time induced measurement bias, there is a need to generate evidence that is based on uniform data analysis, and, standardization methodology presented in this study is a step in that direction. However, this methodology needs to be adopted with caution because the analyst defined time period used to determine the controlled wear-time (equation A: $wt_{CON}$) will have an impact on the estimates of accelerometer outcomes.

The criteria to determine controlled wear-time should depend on the research question. In this study, the primary goal of data standardization was to understand and minimize the impact of wear-time variation on different activity intensities. This was achieved by comparing these intensities before and after data standardization. In principle, to execute such a comparison, the controlled wear-time could be determined by using any analyst defined time period (8, 10, 12 hours etc…). However, since the criteria to qualify a day of accelerometry as a valid day was a minimum wear-time of 10 hours/day, this time period was deemed to be most pragmatic to determine controlled wear-time.

## Conclusion

Accelerometry is undoubtedly a vast improvement over self-reported measures of PA and SED; however, it is important to realize that wear-time plays a critical role in determining activity measurement in accelerometry. This study's findings indicate that if substantiated observations are to be made within populations, and valid comparisons are to be made between populations, there is a need to not only explore wear-time variation in detail, but also to minimize the measurement bias caused by this variation.

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## Key points

- Systematic variation in accelerometer wear-time both, within and between participants results in measurement bias.
- Standardization of data after controlling for wear-time produces stable outcome variables.
- Descriptive and multivariate analyses conducted with standardized outcome variables minimize measurement bias.

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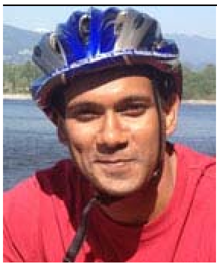

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