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## Sampling frequency impacts the measurement of walking activity after stroke

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### Abstract

The purpose of this study was to examine the effect of sampling epoch on total time spent walking and number of walking bouts/day in persons with stroke. 98 persons post-stroke with average age of 63.8±10.3 years and 43.6±58.1 months post-stroke participated in this study. Participants wore a StepWatch Activity Monitor (SAM) for 3–5 consecutive days. The number of strides taken was collected in consecutive 5 second epochs and down sampled into 10, 20, 30, and 60 second epochs. Total time walking and total number of walking bouts were determined for each day. Low and high activity days were determined as days below and above the 25<sup>th</sup> and 75<sup>th</sup> percentile of total steps/day, respectively. Total time walking and total number of bouts were different for each sampling epoch ( $p < 0.001$  for all). The 5 second sampling epoch resulted in calculation of ~40% of the walking time and ~6 times as many bouts as a 60 second sampling epoch. Differences were greater for low activity days ( $p < 0.001$  for all). Sampling epoch affects the calculation of daily step activity variables whose calculation depends on time, especially during low activity days. Sampling epoch must be carefully considered when designing studies aimed at understanding patterns of daily walking activity.

### Keywords

Ambulation; CVA; Hemiparesis; Hemiplegia; Locomotor activity; Neurological Disorders; Physical activity; Physical exercise; Stroke; Walking

### Introduction

Approximately 80% of the 5.5 million people living with stroke have some level of disability<sup>1</sup>. This disability is a consequence of, and a risk factor for, physical inactivity<sup>2, 3</sup>. Lack of physical activity has serious health and functional consequences for people post

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#### Author Contributions

BK processed and analyzed the data and prepared the manuscript. MR collected and analyzed the data and edited the manuscript. DR conceived the study, analyzed the data, and prepared the manuscript.

stroke<sup>4</sup>. Therefore, a thorough and accurate measurement of inactivity after stroke is necessary to develop optimal interventions to improve activity.

To obtain objective measurement of walking activity after stroke, many studies utilize an accelerometry-based system<sup>5</sup>. Several studies have established the reliability and accuracy of these devices in persons with stroke<sup>6-8</sup> and have emphasized the importance of the ability to adjust measurement properties of the device (e.g.-sensitivity to motion) to enhance accurate measurement<sup>6,7</sup>. One measurement property, however, that has not received systematic investigation is the sampling epoch. While the length of the sampling epoch will not affect the calculation of steps per day, as studies begin to analyze step activity data in a more detailed way<sup>9,10</sup>, the length of the sampling epoch becomes critical<sup>11,12</sup>. For example, the calculation of the amount of time spent walking is highly dependent upon sampling epoch. Consider two studies of walking activity after stroke. In one study, the sampling interval is set to 60 seconds<sup>13</sup> and in the other it is set to 15 seconds<sup>14</sup>. Now imagine that a participant in each study took several steps in a row, amounting to 7 seconds of continuous walking, and then sat down. In the study where the sampling epoch was set to 60 seconds, the subject would be given credit for 60 seconds of walking, since the system cannot detect time intervals shorter than 60 seconds. In contrast, in the study where the sampling epoch was set to 15 seconds, the subject would be given credit for 15 seconds of walking, much closer to the actual time spent walking.

This overestimation of time spent walking when using a longer sampling epoch is particularly problematic in calculations aimed at comparing different groups of subjects. The purpose of this study was to systematically examine the effect of sampling epoch on total time spent walking and number of walking bouts per day in persons with stroke. We hypothesized that the use of longer sampling epochs would result in an overestimate of the time spent walking and an underestimate of the number of discrete walking bouts and that the magnitude of this over/underestimation due to longer sampling epochs would be greater when the number of steps per day was low.

## Methods

### Participants

Individuals post-stroke living in the community over the age of 18 who had experienced one or more strokes participated. Individuals were excluded if they had additional neurologic diagnoses, were unable to walk without assistance from another person (orthotics and assistive devices allowed), or were unable to follow instruction or communicate with investigators. All included individuals signed informed consent approved by the Human Subjects Review Board at University of Delaware prior to participation.

### Procedures

A StepWatch Activity Monitor (SAM) (Orthocare Innovations, Seattle, Washington) was calibrated to a subject's height and weight and placed above the subject's ankle on the non-paretic leg. Calibration was checked with 30 strides at a subject's self-selected walking speed and 10 strides at a faster speed. The SAM was recalibrated if the stride count differed

by >2 between the SAM and manual counting. Participants wore the SAM during all waking hours (except bathing and swimming) for 3–5 consecutive days. The number of strides taken was collected in consecutive 5 second epochs.

### Data analysis

Prior to data analysis, all data from the SAM was reviewed to eliminate partial days (e.g.- days when the subject did not wear the SAM during all waking hours). The SAM data were processed using a custom-written MATLAB program (MathWorks, Natick, MA). Data recorded by the SAM in strides was converted to steps for analysis within the program by multiplying by a factor of 2. Data collected in 5 second epochs were down sampled into 10, 20, 30, and 60 second sampling epochs to investigate the effect of sampling frequency. For each day collected, the total time walking and the total number of walking bouts were calculated at each of the 5 sampling rates. Total time walking was calculated as the total number of sampling epochs during which at least one stride was recorded multiplied by the length of the sampling epoch. The total number of walking bouts was calculated as the sum of discrete walking bouts, with the start of a walking bout defined as a sampling epoch with activity (non-zero) and the end of a bout defined as a sampling epoch with no activity (zero strides).

Data were normalized to the 60 second sampling epoch. A repeated measures ANOVA was used to assess differences between the five sampling rates for both the normalized time walking and normalized number of bouts. Post-hoc paired t-tests were performed to assess significance between individual sampling epochs.

To analyze the influence of amount of walking activity on the relationship between sampling rates, days in which the total number of steps fell below the 25<sup>th</sup> percentile were classified as low activity days. Similarly, days in which the total number of steps was greater than the 75<sup>th</sup> percentile were classified as high activity days. Post-hoc paired t-tests were run comparing the time walking and number of bouts between low and high activity days for all sampling epochs. The significance level for the repeated measures ANOVA was set at 0.05. A Bonferroni correction was applied for the post-hoc paired t-test with 10 comparisons, yielding a significance level of 0.005.

### Results

Ninety-eight subjects (Male: n=59) with the average age of  $63.8 \pm 10.3$  years, average gait speed of  $0.67 \pm 0.29$  meters per second, and  $43.6 \pm 58.1$  months post stroke participated in this study, resulting in a total of 366 days sampled. Subjects walked an average of  $5432 \pm 3727$  steps per day. Total time walking and total number of bouts were different for each sampling epoch ( $p < 0.001$  for all cases). The 5 second sampling epoch resulted in calculation of ~40% of the walking time of a 60 second sampling epoch (Figure 1a, Table 1) and ~6 times as many bouts as a 60 second sampling epoch (Figure 2a).

When comparing low activity (<2500 steps, n=93) and high activity (>7500 steps, n=86) days, the percent change in walking time and number of bouts was greater for the low activity days from the 5 second sampling epoch to each subsequent higher sampling epoch

(all comparisons  $p < 0.001$ , Figure 1b, 2b). This indicates that the over/underestimation that occurs with the longer sampling epochs was worse for the low activity days.

## Discussion

The results of this study show that the effect of the length of the sampling epoch differed based on the amount of walking activity performed. The impact of sampling epoch was greater for the days with low activity (<2500 steps) compared to those with high activity (>7500 steps). The result of this is that differences between groups with largely different number of steps/day would be compressed when larger sampling epochs are chosen (Figures 1c and 2c). This has potential implications for the interpretation of step activity data comparisons between groups of subjects with largely different number of steps/day, such as sedentary and active older adults<sup>15</sup> or adults with stroke compared to neurologically intact adults<sup>9</sup>.

The selection of epoch size is also important when comparing subjects who take a similar number of steps per day, but have different activity patterns. As an example, the analysis of two subjects that walked a similar number of steps in a day is shown in Table 2. When using 60 second epochs to analyze their walking patterns, it is calculated that subject Y walked for 1 hour longer than subject X, in only 9 greater bouts (20% more bouts). In contrast, when analyzing the data with 5 second bouts, it is calculated that subject Y walked only ~8 mins (0.13 hrs.) longer than subject X, while participating in 110 more bouts (35% more bouts). For these subjects, the selection of epoch duration has a meaningful influence on the subjects' calculated activity level, despite walking a similar number of steps.

Many studies that examine daily step activity using an accelerometry-based device in persons with stroke do not report the sampling epoch used<sup>7, 16, 17</sup>, and may use the default epoch set by the company (e.g.- 60 sec epoch for the SAM device). While this choice may be appropriate for measurement of steps/day, the results of this study suggest that it may not be optimal when examining the time spent walking or number of bouts per day. Moreover, it is likely that other measurements, such as step intensity<sup>10</sup>, where the time interval is important in the calculation, are also impacted by the choice of sampling epoch. A measurement such as cadence, which describes the rate of steps taken, is highly dependent on sampling epoch. For example, if an individual takes 5 steps in a 5 second epoch and rests for a minute, they would have a cadence of 1 step per second during the 5 second epoch of activity. If the data was collected in 60 second epochs, however, those same 5 steps would result in a cadence of 5 steps per 60 seconds, or 0.083 steps per second, a much lower cadence for the same activity. For some devices, longer sampling epochs result in the storage of a fewer number of days of walking<sup>11, 12</sup>, so it is necessary to strike a balance between recording an adequate number of days of walking<sup>18</sup> with the need to use an appropriate sampling frequency.

## Conclusions

The length of the sampling epoch affects the calculation of daily step activity variables whose calculation depends implicitly or explicitly on time. The size of this effect varies

depending on the amount of daily step activity. Therefore, the sampling epoch must be carefully considered when designing studies aimed at understanding patterns of daily walking activity.

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## Abbreviations

**SAM** Step Activity Monitor

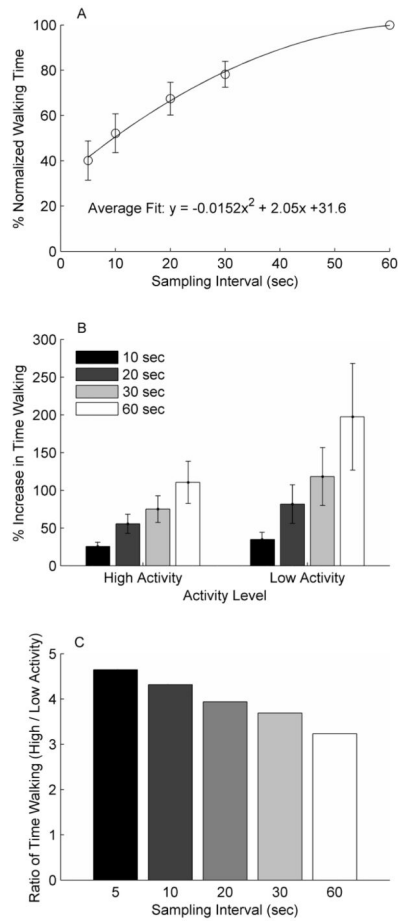
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### JRRD at a Glance

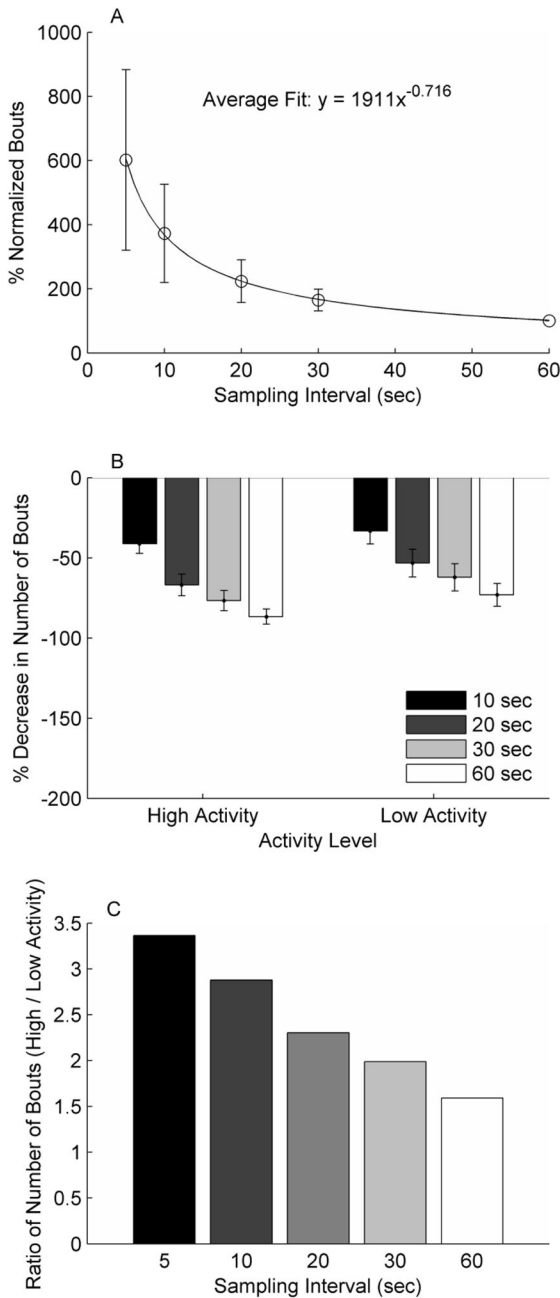
Lack of physical activity has serious health and functional consequences for people post stroke. Therefore, interventions to improve post-stroke activity and accurate methods to measure activity are needed. The purpose of this study was to examine how the length of the interval over which activity data is sampled affects the measurement of activity. The results showed that the length of the sampling interval results in over or underestimation of activity and this is worse when activity is low, which could impact the interpretation of comparisons between groups of people with largely different amounts of activity.



**Figure 1.**

(A) Time spent walking per day normalized to the time calculated using 60 second sampling epochs. Significant differences were found between all sampling epochs. (B) Percent increase in time walking per day compared to the 5 second sampling epoch in the high (>7500 steps/day) and low (<2500 steps/day) activity days. (C) Ratio of time walking between high and low activity days at all sampling epochs. Notice that the difference between high and low activity days is reduced with each subsequently larger sampling epoch.





**Figure 2.**

(A) Number of walking bouts per day normalized to the 60 second sampling epoch. Significant differences were found between all sampling epochs. (B) Percent decrease in number of bouts per day compared to the 5 second sampling epoch in the high (>7500 steps/day) and low (<2500 steps/day) activity days. (C) Ratio of the number of bouts between high and low activity days at all sampling epochs. Notice that the difference between high and low activity days is reduced with each subsequently larger sampling epoch.

**Table 1**

Calculated time spent walking and total number of bouts per day for the 5 epoch lengths analyzed.

Bout Length	Time Walking/Day (hrs)		Number of Bouts/Day	
	<i>Average</i>	<i>SD</i>	<i>Average</i>	<i>SD</i>
5 sec	1.65	0.97	356.25	196.40
10 sec	2.14	1.21	223.77	119.55
20 sec	2.76	1.50	135.31	67.63
30 sec	3.18	1.68	100.08	46.92
60 sec	4.02	2.00	60.22	25.51

Example day of activity for two subjects with similar steps within the day. Steps, time walking, and number of bouts for the day across the 5 epoch lengths analyzed.

Table 2

Bout Length Subject	Steps		Time Walking (hrs)		Number of Bouts	
	X	Y	X	Y	X	Y
5 sec	4778	4858	1.45	1.58	308	418
10 sec	4778	4858	1.87	2.16	179	266
20 sec	4778	4858	2.34	2.92	106	150
30 sec	4778	4858	2.72	3.43	74	114
60 sec	4778	4858	3.35	4.35	53	64