Title: **An exploration of sedentary behavior patterns in community dwelling people with stroke. A cluster-based analysis.**

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ABSTRACT

Background and Purpose: Long periods of daily sedentary time, particularly accumulated in long uninterrupted bouts, are a risk factor for cardiovascular disease. People with stroke are at high risk of recurrent events and prolonged sedentary time may increase this risk. We aimed to explore how people with stroke distribute their periods of sedentary behavior, which factors influence this distribution, and whether sedentary behavior clusters can be distinguished?

Methods: Secondary analysis of original accelerometry data from adults with stroke living in the community. We conducted data-driven clustering analyses to identify unique accumulation patterns of sedentary time across participants, followed by multinomial logistical regression to determine the association between the clusters, and the total amount of sedentary time, age, gender, body mass index (BMI), walking speed and wake time.

Results: Participants in the highest quartile of total sedentary time accumulated a significantly higher proportion of their sedentary time in prolonged bouts ($p<0.001$). Six unique accumulation patterns were identified; all of which were characterized by high sedentary time. Total sedentary time, age, gender, BMI and walking speed were significantly associated with the probability of a person being in a specific accumulation pattern cluster, $p<0.001$ – $p=0.002$.

Discussion and Conclusions: Although unique accumulation patterns were identified, there is not just one accumulation pattern for high sedentary time. This suggests that interventions to reduce sedentary time must be individually tailored.

Video Abstract available (see the Video, Supplemental Digital Content 1, available at: "---insert video abstract link here---")

INTRODUCTION

High amounts of sedentary time, defined as any waking behavior characterized by an energy expenditure ≤1.5 Metabolic Equivalent of Task while in a sitting, reclining or lying posture',[1–3] is a well-known health risk. Both the total time spent sedentary each day and the pattern of accumulation of sedentary time; specifically the time spent in long bouts of uninterrupted sedentary time, are associated with increased cardiovascular disease risk.[4–10] Two recent large meta-analyses have found an exponentially increased risk of both cardiovascular disease and all-cause mortality in healthy adults when daily sedentary time exceeds 8-9 hours a day, particularly in people with low levels of physical activity.[11,12] This risk is increased even more when sedentary time is accumulated in prolonged bouts.[4–10] People with stroke fit this high-risk profile with daily sedentary time exceeding 9 hours/day,[13–16] accumulated in long bouts [13–15] and with minimal time spent physically active.[13–17]

The risk of recurrent stroke is up to 40% in the first ten years post onset.[18] Reducing sedentary time is a potential new intervention to reduce recurrent stroke risk.[19] Long bouts of uninterrupted sitting negatively affect blood pressure and glycemic control [4–10,20]; both of which are important risk factors for recurrent stroke.[21,22] However, preliminary data from one study suggests that interrupting prolonged sedentary bouts with frequent, short breaks of light intensity physical activity reduces blood pressure in people with stroke.[23]

Understanding how individuals with stroke accumulate sedentary time is a fundamental step in designing effective interventions to reduce sedentary time. At the time this analysis was planned there was only one published study examining accumulation patterns of sedentary time in people with stroke.[14] The results suggested that people with stroke accumulated most of their sedentary time during the afternoon and evening,[14] but the study did not explore the amount, duration and distribution of sedentary bouts across the day, or individual differences in accumulation patterns.

Therefore, the objective of this study was to explore whether there are differences in the patterns in which people with stroke accumulate sedentary time during waking hours. The specific research questions were;

1) Do people with stroke with the highest quartile of total sedentary time accumulate more of their sedentary time in long bouts, compared with people in the lowest quartile?
2) Are there distinctly different patterns of accumulating sedentary time in people with stroke?
3) Do these unique accumulation patterns differ by total sedentary time?
4) Do these unique accumulation patterns differ by demographic or stroke-related variables?

METHOD

Design

Secondary analysis of original accelerometer data from 9 primary studies involving n=274 participants, from 3 different countries. These were either observational or intervention studies; from the latter we only baseline data was used. Additional information on the included studies and full methods for pooling and harmonization of data are described elsewhere.[24] This study was approved by the Human Research Ethics Committee of The University of Newcastle (H-2016-0427).

Participants and data processing

The inclusion criteria for the studies were: 1) adults with stroke who were living in the community, 2) sedentary time was measured using the activPAL monitor (PAL Technologies Ltd, Glasgow, United Kingdom), 3) the ethical approval and informed consent for the data collection permitted inclusion of the data in this study. We included data from the ActivPAL

(PAL Technologies Ltd, Glasgow, United Kingdom, from now on referred to as Accelerometer-based Activity Monitor, AAM), a 24 hours/day thigh worn accelerometer which is reliable (0.79-0.99 Interclass correlation coefficient) and valid (accuracy is 98-100%) to determine sedentary behavior.[25–27] Lead authors of the primary studies provided the original de-identified participant data, including AAM CSV files, demographic and stroke related variables. All data were combined into one data set for analyses.

To harmonize the AAM data we first determined waking hours using a custom algorithm we developed based on previously published and validated methods.[28] The full methods are published elsewhere.[24] We then excluded participants who had less than 3 days of at least 8 hours/day (waking hours) of AAM data, as this has been determined as the minimum data required for accurate measurement of habitual movement behavior.[29] In the cases where different outcome measures were used for a stroke related or demographic variable, we used validated methods to dichotomize or categorize data – for example into 'independent in Activities of Daily Living (ADL)' or not. More details on the processing and harmonization of AAM data and outcome variables can be found elsewhere.[24]

Analyses

First, we identified how much of the total wake time spent sedentary was accumulated in prolonged bouts. To adjust for different amounts of waking hours we used the percentage of waking hours spent sedentary and spent in prolonged sedentary bouts of over 30 or 60 minutes.[8,10,30,31] Participants with the highest and lowest amounts of sedentary time were identified based on quartiles of total sedentary time data. We used independent t-tests (or Mann-Whitney U tests where data were not normally distributed), to examine differences in the proportion of sedentary time accumulated in >30 and >60-minute bouts between participants in the highest and lowest quartiles of sedentary time. Alpha was set at 0.05, with Bonferoni correction for multiple testing at 0.025.

To determine unique patterns of accumulating sedentary time using the AAM data, we used a '*symbolic time series representation'* method.[32,33] The AAM records movement data as events of type: 0 = lying / sitting (sedentary activity), 1 = standing, and 2 = walking. Event (movement) data were summarized into fixed duration intervals with each interval represented by a letter (t: sedentary, s: standing, w: walking) according to the event type with the most accumulated time in the interval. For example, an interval of 60 seconds with 30 seconds of sedentary time, 15 seconds of standing and 15 seconds of walking would be classified as 't'(sedentary). A letter can represent any predetermined time interval > 15 seconds. Consecutive intervals were then combined to form a linear sequence of letters or a 'word' which represents the pattern of movement during that time period (*P*). The periods thus consist of multiples of intervals of at least 15 seconds. For example, a movement period (*P*) of 15 minutes with 1-minute intervals (*I*) (*P*15*I*1) would consist of 15 separate letters. For instance; 1 minute of standing, 2 minutes sedentary, 3 minutes walking, another 1 minute sedentary, then 8 minutes standing, would be represented by: '*sttwwwtssssssss'*. Movement patterns were formed by a sliding window of a fixed number of intervals (letters) see Figure 1. This method involves moving one interval (letter) at a time across the entire wake time, and then aggregating movement patterns. This method was chosen so as not to predetermine the pattern due to the chosen interval.[32,33]

"---insert Fig 1 about here---"

Our aim was to determine the optimal movement period *(P)* and interval *(I)* that created the most clearly defined clusters. To do this we ran iterative analyses with varying interval (letter) durations of 5, 10, 30, and 60 seconds, and period durations of 6, 12 and 30 intervals. This provided descriptions of movement patterns in period durations ranging from 30 seconds to half an hour. The final interval and period combination was chosen as the one that led to the most clearly defined clusters, and the lowest residuals in the co-variable modelling analyses (described below).

Determining and defining clusters

Based on the movement accumulation patterns of each participant (as described above), clusters were identified based on Euclidean distance metrics on the normalized activity pattern count, using hierarchical clustering with dynamic cuts. A standard dendrogram was generated, and then cut to obtain the clusters with the Hybrid Dynamic Tree Cut method of Langfelder, Zahng and Horvath.[34] We then used multinomial logistic regression with *cluster* as the outcome to determine which variables were associated with the probability of an individual participant belonging to a particular cluster. We included all independent variables available across datasets that had no missing values in them; these were age, gender, BMI and walking speed. To determine the period *(P)* and interval *(I)* combination that was most meaningful, the residual deviance of all the models was determined, the lowest showing the best fit. All analyses were conducted with R statistical software, version 3.3.3 and IBM SPSS statistics version 22.

RESULTS

Data from 274 people with stroke were included in the analyses. The mean age was 66 (SD 13) years, 167 (61%) were male and mean time since stroke was 18 (SD 29) months (see Table 1).

"---insert Table 1 about here---"

Across the whole data set participants spent on average 69 (SD12)% of waking hours sedentary; 56 (SD15)% of sedentary time during waking hours was accumulated in bouts >30 minutes and 32 (SD 17)% in bouts >60 minutes (Table 2). Participants in the highest quartile of total sedentary time (>79% waking hours) accumulated a significantly higher proportion of their sedentary time in >60 and >30 min bouts compared to the participants in the lowest quartile of total sedentary time (<61% waking hours, mean difference >60 min bouts 27% [95% CI 23 to 32], mean difference >30 min bouts 26% [95% CI 22 to 30], (Table 2).

"---insert Table 2 about here---"

Six unique clusters of accumulation pattern were identified across the whole dataset by the dendrogram (Figure 2) and the dotplot (Figure 3). The window period duration of 12 letters and sampling interval of 30 seconds (6 minutes total duration) created the most meaningful clusters with the lowest residuals (residual deviance 168.2). For ease of description we have labelled and named the clusters according to the relative amount of sedentary time and bout durations (either prolonged bout duration or breaking bout duration) (Table 3).

"---insert Fig 2 about here---"
"---insert Fig 3 about here---"
"---insert Table 3 about here---"

High sedentary prolongers on average had the highest proportion of waking hours spent sedentary (86%) and longest bout duration (37 min). We labelled 2 clusters as *high sedentary breakers* as they both had high proportions of waking hours spend sedentary (81% and 74% of waking hours spent sedentary) and frequent bouts of activity (average sedentary bout duration 19- and 16-min, respectively). We labelled 2 clusters as *medium sedentary breakers*, as they both had lower proportions of waking hours spend sedentary (68% and 64%) and frequent bouts of activity (average sedentary bout duration 16- and 13-min, respectively). Finally, we labeled one cluster *low sedentary breakers* as it had the lowest proportion of waking hours spent sedentary (53%) and shortest average sedentary bout duration (10 min) indicating low amounts of prolonged sedentary bouts. In other words, the *high sedentary prolongers* accumulated the highest amount of sedentary time, mostly in long, uninterrupted bouts duration. The *high sedentary breakers* also accumulated high amounts of sedentary time, but in shorter bouts. The average walking speed was slowest in the *high sedentary prolongers* cluster.

The multinomial logistic regression estimates the probability for an individual to belong to each of the 6 clusters characterized above, given the values of the predictor variables. Total sedentary time was significantly associated with the probability of an individual being in a specific cluster ($p<0.001$). Age, gender, body mass index (BMI) and walking speed were significantly associated with the probability of a person being in a specific cluster ($p<0.001$ – 0.002) but wake time duration was not ($p<0.001$ – 0.961).

Compared with the *low sedentary breakers* reference cluster, higher sedentary time was associated with a higher probability of participants being in either the *high sedentary prolongers* or the *high sedentary breakers* clusters. Participants with lower walking speed were more likely to be in the *high sedentary prolongers* or the *medium sedentary breakers* clusters, and those of younger age were more likely to be in the *low sedentary breakers* cluster (Table 3).

DISCUSSION

The results of this study show that people with stroke with the highest amount of total sedentary time accumulate most of their sitting time in prolonged bouts. We identified 6 distinct patterns of accumulation of sedentary time which differed by total daily sedentary time, average bout duration and participants' walking speed. We found a wide variability in total sedentary time and average bout duration across the clusters and there was not one unique cluster for people with high sedentary time.

Our finding that people with stroke with the highest amount of total sedentary time accumulate this time in prolonged bouts suggest that *'high sedentary prolongers'* may have the most to gain from interventions to reduce sedentary time. Two large meta-analyses have shown exponential increases in both cardiovascular and all-cause mortality related to daily sedentary time of 9 hours or more.[11,12] These risk curves suggest that even small reductions in daily sedentary time could lead to substantial reduction in disease risk – but this remains to be tested in clinical trials. There is also evidence that interrupting sitting time with frequent, short bouts of physical activity can have immediate beneficial physiological effects such as reductions in blood pressure and improvements in glucose control in a range of populations,[35] including stroke.[23] However, whether or not people with stroke are able to increase their frequent bouts of physical activity in order to break up sedentary time in the long-term, and whether this has an effect on reducing stroke risk has not yet been tested.

While we found 6 distinct clusters of patterns of accumulation of sedentary time, they varied less than we expected in total sedentary time. Three clusters (*high sedentary time prolongers* and *high sedentary time breakers [1]* and *[2]*) included an average of 74 to 86% of waking hours spent sedentary. This means that though there are similarities in the unique movement patterns of people with higher or lower amounts of sedentary time there is not one distinct pattern for each of them. We found that older age, higher BMI and slower walking speed were related to a higher probability of being in a cluster defined by high total sedentary time and long sedentary bout duration. This is largely in agreement with our previous work[24] and that of others.[15,36] While this might indicate that these people are more likely to spend long periods of the day in uninterrupted sitting time, it is unlikely that we could be able to predict high sitting time using these variables. Instead, clinicians should first assess an individual's daily sedentary time, preferably using objective accelerometer-based measures, then provide individualized interventions to reduce sedentary time.

To date, only 2 trials have been published that have tested interventions to encourage people with stroke to reduce or break up their daily sitting time. One small randomized trial showed that people with stroke reduced their daily sitting time (measured by accelerometry) in response to a coaching intervention, but not significantly more than the attention-matched control group.[37] Another small, non-controlled trial also found reductions in sedentary time in response to a coaching intervention.[38] Both of these trials were designed to test safety and feasibility and were not powered to test efficacy. Further work is needed to carefully design and test interventions to reduce sedentary time in people with stroke, since they are more sedentary than their healthy peers.[13,16] Our results suggest that these interventions should target the *high sedentary prolongers* and *high sedentary breakers* groups in particular (these groups constituted 51% of our sample). Interventions should focus on both reducing sedentary time and interrupting long sedentary bouts. Furthermore, while our results provide some information about characteristics of these groups, the similarities between groups are more striking than the differences. For example, obese (average BMI 30.1 kg/m^2) stroke survivors with very slow walking speed (average 0.6 m/s) are more likely to be *high sedentary prolongers*. However, those who are near-normal BMI or overweight (average BMI 25.4 to 29.3 kg/m^2) with near-normal walking speeds (0.8 to 1.1 m/s) may also be spending large amounts of their day sedentary (64-81% waking hours). The take-home message from these results is that all people after stroke should have their sedentary and activity time objectively measured to determine their level of risk.

Our group is using results from this and other[15,24] studies we have completed to design an intervention to reduce sedentary time after stroke.

Limitations

Our sample consisted primarily of older adults more than 6 months post-stroke who were independent in activities of daily living and walked with near-normal speed (average walking speed 0.9 (0.4) m/s). Around 26% of included participants lived alone. We only included participants for whom we had at least 3 days of valid activity monitor data, so we can be confident our data are representative of usual activity levels in this group. This method of using a pooled dataset allowed us to use a data-driven method of clustering analyses to determine unique patterns of the accumulation of sedentary time. It is important to note that this was exploratory analyses from 9 original primary studies. Our sample size was large (n=274) and came from 3 different countries, increasing the generalizability of our findings. However, we did not have any participant data from low to middle income countries. The three countries where the studies were conducted were Australia, the United Kingdom and Canada. While there may be some differences across countries in terms of environmental and cultural drivers of physical activity, we do not expect these to be of significant influence on the results. We checked this in our previous analyses (by using ‘study’ as an independent variable).[24] The data-driven method of determining clusters of sedentary time patterns minimizes the influence of researcher bias, but means that the clusters found were difficult to clearly define.

CONCLUSIONS

In conclusion this study shows that people with high total sedentary time also accumulate this time in prolonged, uninterrupted bouts. Although unique accumulation pattern clusters were identified, high sedentary time was a feature for many of them. Individual assessment and tailoring of interventions to reduce sedentary time is required.

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Table 1 Participant characteristics

Characteristic	n participants (n studies)	Mean (SD) or n (%)
Age *(yr)*,	274 (9)	66 (13)
Gender, number female	274 (9)	107 (39)
Time since stroke *(mth)*	268 (8)	18 (29)
BMI *(kg/m^2)*,	205 (7)	27 (5.5)
Walking speed *(m/s)*,	195 (6)	0.9 (0.4)
Living alone, number yes	144 (6)	38 (26%)
Independent in ADL, number yes	197 (6)	153 (88%)

Abbreviations: BMI, body mass index; ADL, Activities of Daily Living

Table 2. Differences in bout duration, expressed as percentage of waking hours. Values are means (SD) for groups and mean (95% confidence interval) for differences between groups.

Bouts	Whole sample (n=274)	Groups		Difference between groups
		Highest quartile sitting time (n=68)	Lowest quartile sitting time (n=68)	Highest quartile minus lowest quartile
>30 min	56% (15)	69% (11)	44% (13)	26% (22 to 30)
>60 min	31% (17)	47% (16)	20% (12)	27% (23 to 32)

P<0.001 for all between group differences

Table 3 Characteristics of clusters

	High sedentary prolongers (n=21)	High sedentary breakers *(1)* (n=55)	High sedentary breakers *(2)* (n=65)	Medium sedentary breakers *(1)* (n=22)	Medium sedentary breakers *(2)* (n=42)	Low sedentary breakers (n=69)
Gender, number female (%)	10 (48)[a] -	18 (33)[a]* -	25 (38)[a]* +	8 (36)[a] -	15 (36)[a] +	31 (45)
Age *(yr)*, mean (SD)	69 (11)[a] +	67 (14)[a] +	65 (13)[a] +	69(14)[a] +	69 (14)[a] +	64 (13)
BMI *(kg/m^2)* mean (SD)	30.1 (5.3)[a] +	27.3 (6.5)[a] -	28.1 (5.1)[a] -	29.3 (6.9)[a] +	25.4 (3.6)[a]* -	26.2 (5.0)
Walking speed *(m/s)* mean (SD)	0.6 (0.4)[a] -	0.8 (0.3)[a] +	0.9 (0.4)[a] +	0.9 (0.4)[a] -	1.1 (0.4)[a] +	1.1 (0.5)
Wake time *(hr)* mean (SD)	14 (2)[a] +	13 (1)[a] -	14 (2)	14 (1)	14 (2)	15 (1)
Total sitting time *(% waking hr)* mean (SD)	86 (3)[a] +	81 (3)[a] +	74 (4)[a] +	68 (4)[a] +	64 (5)[a] +	53 (8)
Sedentary bout duration (*min*) mean (SD) [b]	37 (5)	19 (8)	16 (11)	16 (6)	13 (6)	10 (5)
Total standing time *(% waking hr)* mean (SD)[b]	11(4)	14 (3)	19 (3)	26 (3)	26 (6)	35 (8)

[a] Significant association with the probability to belong to this cluster in comparison to the reference cluster 'Low sedentary breakers', multinominal logistic regression, p<0.05.
+/- Shows the direction of the probability change, i.e. the direction of the regression coefficient.

[b] Not included in the multinomial logistic regression.

Figure 1. Symbolic time series representation with sliding window

Figure 2. Dendogram hierarchical clustering

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Supplemental Digital Content 1. Video abstract Patterns Sedentary behaviour after stroke