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

Authors:

Wendy Hendrickx^{1,2,3} MSc, Carlos Riveros⁴ PhD, Torunn Askim⁵ PhD, Johannes B.J. Bussmann⁶ PhD, Michele L. Callisaya⁷ PhD, Sebastien F.M. Chastin^{8,9} PhD, Catherine Dean¹⁰ PhD, Victor Ezeugwu¹¹ PhD, Taryn M. Jones¹⁰ PhD, Suzanne S. Kuys¹² PhD, Niruthikha Mahendran¹³ PhD, Patricia J. Manns¹¹ PhD, Gillian Mead¹⁴ PhD, Sarah A. Moore¹⁵ PhD, Lorna Paul⁸ PhD, Martijn F. Pisters^{1,3,16} PhD, David H. Saunders¹⁷ PhD, Dawn B. Simpson² PhD, Zoë Tieges^{8,18} PhD, Olaf Verschuren¹⁹ PhD, Coralie English^{2,20} PhD

1. Department of Rehabilitation, Physiotherapy Science & Sport, UMC Utrecht Brain Center, University Medical Center Utrecht, Utrecht University, The Netherlands

2. School of Health Sciences and Priority Research Centre for Stroke and Brain Injury, Faculty of Health and Medicine, University of Newcastle Australia

3. Center for Physical Therapy Research and Innovation in Primary Care, Julius Health Care Centers, The Netherlands

4. Bioinformatics, Hunter Medical Research Institute, and School of Medicine and Public Health, University of Newcastle Newcastle Australia

5. Department of Neuromedicine and Movement Science, Faculty of Medicine and Health Science, NTNU, Norwegian University of Science and Technology, Trondheim, Norway

6. *Department of Rehabilitation Medicine Erasmus MC University Medical Center, Rotterdam, The Netherlands*
7. *Menzies Institute for Medical Research, University of Tasmania, Hobart, Tasmania, Australia*
- 8 *School of Health and Life Sciences, Glasgow Caledonian University, UK*
9. *Department of Movement and Sports Sciences, Faculty of Medicine and Health Science, Ghent University, Ghent, Belgium*
10. *Department of Health Professions, Faculty of Medicine and Health Sciences, Macquarie University, Australia*
11. *Faculty of Rehabilitation Medicine, University of Alberta, Edmonton, Canada.*
12. *National Head, School of Allied Health, Faculty of Health Sciences Australian Catholic University, Brisbane, Australia*
13. *Discipline of Physiotherapy, Faculty of Health, University of Canberra, Australia*
14. *Centre for Clinical Brain Sciences, University of Edinburgh, UK*
15. *Stroke Research Group, Translational and Clinical Research Institute, Newcastle University, UK*
16. *Department of Health Innovations and Technology, Fontys University of Applied Sciences, Eindhoven, The Netherlands*
17. *Physical Activity for Health Research Centre, Institute for Sport, Physical Education and Health Sciences, University of Edinburgh, Edinburgh, UK*
18. *Department of Geriatric Medicine, University of Edinburgh, UK*
19. *UMC Utrecht Brain Center, Center of Excellence for Rehabilitation Medicine, De Hoogstraat Rehabilitation, University Medical Center Utrecht, Utrecht University, The Netherlands*

20. Centre for Research Excellence in Stroke Recovery and Rehabilitation, Florey Institute of Neuroscience and Hunter Medical Research Institute, Newcastle, Australia

Corresponding Author: Wendy Hendrickx, MSc

Department of Rehabilitation, Physiotherapy Science & Sport, UMC Utrecht Brain Center, University Medical Center Utrecht, Utrecht University, The Netherlands

Center for Physical Therapy Research and Innovation in Primary Care, Julius Health Care Centers, The Netherlands

Address for correspondence: Center for Physical Therapy Research and Innovation in Primary Care, Julius Health Care Centers, Emile Hullebroeckstraat 60, 3543 BZ Utrecht, The Netherlands

Phone: +32 6 23837424 E-mail: W.Hendrickx@umcutrecht.nl

In case of absence of the corresponding author: Coralie English, PhD

Associate Professor, School of Health Sciences and Priority Research Centre for Stroke and Brain Injury, University of Newcastle

Centre for Research Excellence in Stroke Recovery and Rehabilitation, Florey Institute of Neuroscience and Hunter Medical Research Institute

Address for correspondence: School of Health Sciences, University of Newcastle, University Drive, Callaghan NSW 2380, Australia

Phone: +61 2 4913 8102 E-mail: coralie.english@newcastle.edu.au

Correspondence (for review):

Name	Wendy Hendrickx, MSc
Department	1) Department of Physical Therapy

	2) Department of Rehabilitation, Physiotherapy Science & Sport, UMC Utrecht Brain Center
Institution	1) Center for Physical Therapy Research and Innovation in Primary Care, Julius Health Care Centers, Utrecht, The Netherlands 2) University Medical Center Utrecht, Utrecht University, The Netherlands
Country	The Netherlands
Tel	+32 6 23837424
Mob	+32 6 23837424
Fax	Not applicable
Email	W.Hendrickx@umcutrecht.nl

Full correspondence (for publication):

Name	Wendy Hendrickx, MSc
Department	1) Department of Physical Therapy 2) Department of Rehabilitation, Physiotherapy Science & Sport, UMC Utrecht Brain Center
Institution	1) Center for Physical Therapy Research and Innovation in Primary Care, Julius Health Care Centers, Utrecht, The Netherlands 2) University Medical Center Utrecht, Utrecht University The Netherlands
Country	The Netherlands
Email	W.Hendrickx@umcutrecht.nl

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1 **ABSTRACT**

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

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

12 **Results:** Participants in the highest quartile of total sedentary time accumulated a
13 significantly higher proportion of their sedentary time in prolonged bouts ($p < 0.001$). Six
14 unique accumulation patterns were identified; all of which were characterized by high
15 sedentary time. Total sedentary time, age, gender, BMI and walking speed were significantly
16 associated with the probability of a person being in a specific accumulation pattern cluster,
17 $p < 0.001$ – $p = 0.002$.

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

21

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

24

25

26 INTRODUCTION

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

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

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

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

54

55 1) Do people with stroke with the highest quartile of total sedentary time accumulate more of
56 their sedentary time in long bouts, compared with people in the lowest quartile?

57 2) Are there distinctly different patterns of accumulating sedentary time in people with
58 stroke?

59 3) Do these unique accumulation patterns differ by total sedentary time?

60 4) Do these unique accumulation patterns differ by demographic or stroke-related variables?

61

62 **METHOD**

63 *Design*

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

70

71 *Participants and data processing*

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

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

82

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

92

93 *Analyses*

94 First, we identified how much of the total wake time spent sedentary was accumulated in
95 prolonged bouts. To adjust for different amounts of waking hours we used the percentage of
96 waking hours spent sedentary and spent in prolonged sedentary bouts of over 30 or 60
97 minutes.^{8,10,30,31} Participants with the highest and lowest amounts of sedentary time were
98 identified based on quartiles of total sedentary time data. We used independent t-tests (or
99 Mann-Whitney U tests where data were not normally distributed), to examine differences in
100 the proportion of sedentary time accumulated in >30 and >60-minute bouts between

101 participants in the highest and lowest quartiles of sedentary time. Alpha was set at 0.05, with
102 Bonferoni correction for multiple testing at 0.025.

103

104 To determine unique patterns of accumulating sedentary time using the AAM data, we used a
105 ‘*symbolic time series representation*’ method.^{32,33} The AAM records movement data as events
106 of type: 0 = lying / sitting (sedentary activity), 1 = standing, and 2 = walking. Event
107 (movement) data were summarized into fixed duration intervals with each interval represented
108 by a letter (t: sedentary, s: standing, w: walking) according to the event type with the most
109 accumulated time in the interval. For example, an interval of 60 seconds with 30 seconds of
110 sedentary time, 15 seconds of standing and 15 seconds of walking would be classified as
111 ‘t’(sedentary). A letter can represent any predetermined time interval > 15 seconds.

112 Consecutive intervals were then combined to form a linear sequence of letters or a ‘word’
113 which represents the pattern of movement during that time period (*P*). The periods thus
114 consist of multiples of intervals of at least 15 seconds. For example, a movement period (*P*) of
115 15 minutes with 1-minute intervals (*I*) (*P15I1*) would consist of 15 separate letters. For
116 instance; 1 minute of standing, 2 minutes sedentary, 3 minutes walking, another 1 minute
117 sedentary, then 8 minutes standing, would be represented by: ‘*sttwwwtsssssss*’. Movement
118 patterns were formed by a sliding window of a fixed number of intervals (letters) see Figure 1.
119 This method involves moving one interval (letter) at a time across the entire wake time, and
120 then aggregating movement patterns. This method was chosen so as not to predetermine the
121 pattern due to the chosen interval.^{32,33}

122

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

124

125 Our aim was to determine the optimal movement period (*P*) and interval (*I*) that created the

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

132

133 *Determining and defining clusters*

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

146

147 **RESULTS**

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

151

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

153

154 Across the whole data set participants spent on average 69 (SD12)% of waking hours
155 sedentary; 56 (SD15)% of sedentary time during waking hours was accumulated in bouts >30
156 minutes and 32 (SD 17)% in bouts >60 minutes (Table 2). Participants in the highest quartile
157 of total sedentary time (>79% waking hours) accumulated a significantly higher proportion of
158 their sedentary time in >60 and >30 min bouts compared to the participants in the lowest
159 quartile of total sedentary time (<61% waking hours, mean difference >60 min bouts 27%
160 [95% CI 23 to 32], mean difference >30 min bouts 26% [95% CI 22 to 30], (Table 2).

161

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

163

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

170

171 "---insert Fig 2 about here---"

172 "---insert Fig 3 about here---"

173 "---insert Table 3 about here---"

174

175 *High sedentary prolongers* on average had the highest proportion of waking hours spent

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

189

190 The multinomial logistic regression estimates the probability for an individual to belong to
191 each of the 6 clusters characterized above, given the values of the predictor variables. Total
192 sedentary time was significantly associated with the probability of an individual being in a
193 specific cluster ($p < 0.001$). Age, gender, body mass index (BMI) and walking speed were
194 significantly associated with the probability of a person being in a specific cluster ($p < 0.001 -$
195 0.002) but wake time duration was not ($p < 0.001 - 0.961$).

196

197 Compared with the *low sedentary breakers* reference cluster, higher sedentary time was
198 associated with a higher probability of participants being in either the *high sedentary*
199 *prolongers* or the *high sedentary breakers* clusters. Participants with lower walking speed
200 were more likely to be in the *high sedentary prolongers* or the *medium sedentary breakers*

201 clusters, and those of younger age were more likely to be in the *low sedentary breakers*
202 cluster (Table 3).

203

204 **DISCUSSION**

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

211

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

224

225 While we found 6 distinct clusters of patterns of accumulation of sedentary time, they varied

226 less than we expected in total sedentary time. Three clusters (*high sedentary time prolongers*
227 and *high sedentary time breakers* [1] and [2]) included an average of 74 to 86% of waking
228 hours spent sedentary. This means that though there are similarities in the unique movement
229 patterns of people with higher or lower amounts of sedentary time there is not one distinct
230 pattern for each of them. We found that older age, higher BMI and slower walking speed were
231 related to a higher probability of being in a cluster defined by high total sedentary time and
232 long sedentary bout duration. This is largely in agreement with our previous work²⁴ and that
233 of others.^{15,36} While this might indicate that these people are more likely to spend long periods
234 of the day in uninterrupted sitting time, it is unlikely that we could be able to predict high
235 sitting time using these variables. Instead, clinicians should first assess an individual's daily
236 sedentary time, preferably using objective accelerometer-based measures, then provide
237 individualized interventions to reduce sedentary time.

238

239 To date, only 2 trials have been published that have tested interventions to encourage people
240 with stroke to reduce or break up their daily sitting time. One small randomized trial showed
241 that people with stroke reduced their daily sitting time (measured by accelerometry) in
242 response to a coaching intervention, but not significantly more than the attention-matched
243 control group.³⁷ Another small, non-controlled trial also found reductions in sedentary time in
244 response to a coaching intervention.³⁸ Both of these trials were designed to test safety and
245 feasibility and were not powered to test efficacy. Further work is needed to carefully design
246 and test interventions to reduce sedentary time in people with stroke, since they are more
247 sedentary than their healthy peers.^{13,16} Our results suggest that these interventions should
248 target the *high sedentary prolongers* and *high sedentary breakers* groups in particular (these
249 groups constituted 51% of our sample). Interventions should focus on both reducing sedentary
250 time and interrupting long sedentary bouts. Furthermore, while our results provide some

251 information about characteristics of these groups, the similarities between groups are more
252 striking than the differences. For example, obese (average BMI 30.1 kg/m²) stroke survivors
253 with very slow walking speed (average 0.6 m/s) are more likely to be *high sedentary*
254 *prolongers*. However, those who are near-normal BMI or overweight (average BMI 25.4 to
255 29.3 kg/m²) with near-normal walking speeds (0.8 to 1.1 m/s) may also be spending large
256 amounts of their day sedentary (64-81% waking hours). The take-home message from these
257 results is that all people after stroke should have their sedentary and activity time objectively
258 measured to determine their level of risk.

259 Our group is using results from this and other^{15,24} studies we have completed to design an
260 intervention to reduce sedentary time after stroke.

261

262 *Limitations*

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

276 the results. We checked this in our previous analyses (by using ‘study’ as an independent
277 variable).²⁴ The data-driven method of determining clusters of sedentary time patterns
278 minimizes the influence of researcher bias, but means that the clusters found were difficult to
279 clearly define.

280

281 **CONCLUSIONS**

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

286

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299

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413

414 Table 1 Participant characteristics

Characteristic	n participants (n studies)	Mean (SD) or n (%)
Age (<i>yr</i>),	274 (9)	66 (13)
Gender, number female	274 (9)	107 (39)
Time since stroke (<i>moth</i>)	268 (8)	18 (29)
BMI (<i>kg/m²</i>),	205 (7)	27 (5.5)
Walking speed (<i>m/s</i>),	195 (6)	0.9 (0.4)
Living alone, number yes	144 (6)	38 (26%)
Independent in ADL, number yes	197 (6)	153 (88%)

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

416

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

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

419 P<0.001 for all between group differences

420

421 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)

422 ^a Significant association with the probability to belong to this cluster in comparison to the
423 reference cluster 'Low sedentary breakers', multinominal logistic regression, p<0.05.

424 +/- Shows the direction of the probability change, i.e. the direction of the regression
425 coefficient.

426 ^b Not included in the multinomial logistic regression.

427 Figure 1. Symbolic time series representation with sliding window

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429

430 Figure 2. Dendogram hierarchical clustering

431 Figure 3. Dotplot clusters hierarchical clustering

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