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Predictors of Non-Stepping Time in People with Chronic Stroke

Allison Miller PT, DPT, NCS*[1]; Kiersten McCartney PT, DPT*[1]; Tamara Wright PT, DPT[2];
Darcy Reisman PT, PhD, FAPTA[1,2]
*Co first author

[1]Department of Biomechanics and Movement Science Program, University of Delaware, Newark, Delaware, United States of America
[2]Department of Physical Therapy, University of Delaware, Newark, Delaware, United States of America

Corresponding Author: Darcy S. Reisman, PhD, PT, FAPTA. University of Delaware, 540 South College Avenue, Newark, Delaware 19713. E-mail address: dreisman@udel.edu. Phone: 302-831-0508

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ABSTRACT

Background: Sedentary time is an independent construct from active time. Previous studies have examined variables associated with sedentary time to inform behavior change programs; however, these studies have lacked data sets which encompass potentially important domains.

Objectives: The purpose of this study was to build a more comprehensive model containing previously theorized important predictors of sedentary time and new predictors that have not been explored. We hypothesized that variables representing the domains of physical capacity, psychosocial, physical health, cognition, and environmental would be significantly related to sedentary time in individuals post stroke.

Methods: This was a cross-sectional analysis of 280 individuals with chronic stroke. An activity monitor was used to measure sedentary (i.e., non-stepping) time. Five domains (8 predictors) were entered into a sequential linear regression model: physical capacity (6-Minute Walk Test, assistive device use), psychosocial (Activities Specific Balance Confidence Scale, Patient Health Questionnaire-9), physical health (Charlson Comorbidity Index, body mass index), cognition (Montreal Cognitive Assessment), and environmental (Area Deprivation Index).

Results: The 6-Minute Walk Test ($\beta = -0.39$, $p < 0.001$), assistive device use ($\beta = 0.15$, $p = 0.03$), Patient Health Questionnaire-9 ($\beta = 0.16$, $p = 0.01$) and body mass index ($\beta = 0.11$, $p = 0.04$) were significantly related to non-stepping time in individuals with chronic stroke. The model explained 28.5% of the variability in non-stepping time.

Conclusions: This work provides new perspective on which variables may need to be addressed in programs targeting sedentary time in stroke. Such programs should consider physical capacity, depressive symptoms, and physical health.

Keywords: stroke, walking, physical activity, sedentary, depression, behavior change

INTRODUCTION

Individuals post stroke spend a significantly greater amount of time in sedentary behaviors compared to similarly matched individuals without stroke.[1-5] This is concerning because increased sedentary time is associated with a greater risk for future cardiovascular events[6-9] and mortality.[10-12] In addition, evidence is converging that high sedentary time is associated with these risks independent of active time, suggesting that sedentary time may be its own unique construct.[7, 8, 10, 12] In support of this theory, a large study found a strong dose-response relationship between sitting time and all-cause mortality, even in individuals who reported engaging in ≥ 300 minutes/week of physical activity.[12] This suggests that behaviors that occur outside of active time are critically important for health outcomes and should not be ignored.

These findings also indicate it may be insufficient to solely improve an individual's active time and interventions to address reducing and/or breaking up sedentary time may also need to be implemented to maximize health benefits. Indeed, prior studies in stroke[13] and other populations[14, 15] have demonstrated improvements in markers of cardiometabolic health following breaks in sedentary time. This suggests there are important health benefits associated with intervening on sedentary time.

For these reasons, recent work in stroke has begun to test behavioral interventions specifically targeting sedentary time.[16-18] However, in order for behavior change programs targeting sedentary time to be effective and leverage these health benefits, an understanding of what factors affect sedentary time in people after stroke is needed. As active and sedentary time are different constructs,[7, 8, 10, 12] it logically follows, different variables may need to be addressed in an intervention program targeting sedentary time compared to active time.

A recent review by Hendrickx et al. pooled nine studies examining sedentary behavior in individuals with stroke to examine variables associated with sedentary time.[19] However, the authors were unable to find studies that examined all of their predictors of interest (specifically, environmental and behavioral factors), and their models explained a relatively small percentage (11-19%) of the variance in sedentary time.[19] The authors therefore concluded other variables need to be investigated to fully understand factors associated with sedentary time in this population. This is further corroborated by qualitative work suggesting other variables, such as environmental factors[20] and self-efficacy,[20, 21] affect time spent in sedentary behaviors in individuals with stroke, which were not accounted for in the work by Hendrickx et al.

Therefore, the purpose of this work was to address this knowledge gap by leveraging a large dataset containing many potential predictors of sedentary time in various domains which were not accounted for in previous work to build a more comprehensive model of sedentary time in individuals post stroke. We hypothesized that, after controlling for covariates (age, gender, stroke chronicity), five different domains comprised of eight individual predictors, would be significantly related to sedentary time in people post-stroke, including: measures of physical capacity[19, 22, 23] (6-Minute Walk Test, assistive device use), psychosocial factors[21, 22] (Activities Specific Balance Confidence Scale, Patient Health Questionnaire-9), physical health[19] (Charlson Comorbidity Index, body mass index), cognition[21] (Montreal Cognitive Assessment), and environmental factors[20] (Area Deprivation Index). The results of this work provide new insights on factors that may need to be targeted in behavior change programs addressing sedentary time in individuals with stroke.

METHODS

Study Design and Population

A cross-sectional analysis was conducted using baseline data from a larger multi-site clinical trial (NCT02835313)[24]. The specific objectives of this clinical trial are to test the efficacy of three interventions designed to improve real-world walking activity in individuals with chronic stroke and understand for whom these interventions are most effective. All participants signed informed consent approved by the University of Delaware Institutional Review Board prior to participation in the clinical trial. Recruitment for the clinical trial took place across four sites: University of Delaware (UD), Christiana Care Health System (CCHS), Indiana University (IU), and University of Pennsylvania (UPenn). Inclusion criteria for this study included: ages 21-85 years, ≥ 6-months post-stroke, and ability to walk at self-selected speed of ≥0.3 m/s without assistance from another person. Exclusion criteria included: evidence of a cerebellar stroke, secondary neurological conditions, lower limb Botulinum toxin injection in prior 4 months, current participation in physical therapy, inability to ambulate outside the home prior to stroke, coronary artery bypass graft, stent placement or myocardial infarction within the past 3 months, musculoskeletal pain limiting activity, or inability to communicate with investigators or follow two-step commands. This manuscript conforms to the STROBE Guidelines.

Measures

Since the objective of this work was to build a more comprehensive model of sedentary behavior in stroke and examine variables that have not previously been assessed, we attempted to be as inclusive as possible when selecting variables to include in our statistical model. On the first baseline visit, demographic and stroke information including age, gender, and time since initial stroke (TSIS) were collected. The following measures were also collected at the baseline visit representing five domains of interest: physical capacity (6-Minute Walk Test (6MWT), assistive device use (AD)); psychosocial factors (Patient Health Questionnaire-9 (PHQ-9) and Activities Specific Balance Confidence Scale (ABC)); physical health (Charlson Comorbidity Index (CCI), body mass index (BMI)); environmental (Area Deprivation Index (ADI)); and cognitive function (Montreal Cognitive Assessment (MoCA)). Table 1 summarizes the domains of interest and provides a description of each measure. These domains were intentionally chosen based on reviewing prior literature examining predictors of sedentary time in people with stroke[19-23, 25-27] and based on evidence demonstrating that active time is multifactorial in people with stroke.[28, 29]

Step Activity Monitoring

All participants were provided with a step activity monitor, the Fitbit One™ or Fitbit Zip™ placed at the non-paretic ankle, to measure daily step activity for a minimum of three days.[30] The Fitbit has demonstrated acceptable accuracy in detecting stepping activity in people with stroke.[31-34] Participants were provided with verbal and written instructions to don the device upon waking and doff prior to sleeping, unless the participant was bathing or taking part in water-based activities. Daily reminders were provided via phone call or text message to enhance compliance. Participants were not asked to complete diary entries to record when the device was donned or doffed to minimize participant burden. Participants were instructed to go about their usual activities while wearing the device. Upon returning the device, a trained physical therapist examined the step activity data while the participant was present to ensure a minimum of 3 valid recording days. A valid recording day was defined as a day in which it the participant appeared to wear the monitor during all waking hours. Participants were queried about any inconsistencies or irregularities in the step data in order to determine if a day was valid or not. For example, if a participant consistently demonstrated intermittent stepping activity over the course of 12 hours, followed by a day with minimal stepping activity over the course of 3 hours, the participant was queried to see if they removed the monitor earlier than usual on this day, if they were truly sedentary for the remaining parts of the day, or if any other unusual circumstances occurred.

Since the purpose of this work was focused on sedentary time and not active time, we carefully considered how to operationalize sedentary time. Based on the instructions provided to participants as part of the larger clinical trial, in conjunction with the fact that a minute with 0 steps could represent a number of different behaviors (e.g., sitting, lying, standing), we therefore use the term “non-stepping behavior” to mean any minute of data with 0 steps.

Data Analysis

The first step in data processing was to remove suspected “non-wear” time. The R package “accelerometry” was used to calculate device “wear” and “non-wear” time using a 4-hour non-wear window.[35] “Non-wear” time was defined as a 4-hour time window of 0 steps, accounting for up to 2 minutes of spurious activity with 2 or less steps per minute. All other time was defined as “wear” time. To verify the appropriateness of a 4-hour non-wear interval, an expert clinician (with 16 years of clinical experience and 12 years of research experience using step activity monitors) used their clinical judgement to code non-wear, active, and non-stepping time for 10 randomly selected participants, and results were compared to that of the R code. This resulted in > 85% agreement for all metrics, providing support for a 4-hour non-wear window. “Non-stepping” time was operationalized as any “wear” time minute(s) with 0 steps. For the statistical analysis, non-stepping time was normalized to wear time for each participant and expressed as a percentage.

Statistical Analysis

Sequential linear regression was used to test the relationship between predictors of interest and the percentage of time spent in non-stepping behaviors. This approach was chosen as we conceptualized predictors as existing within five separate domains that were entered into the regression model in the following order: demographic information (block 1: age, gender, TSIS), physical capacity (block 2: 6MWT, AD use), psychosocial (block 3: ABC, PHQ-9), physical health (block 4: CCI, BMI), environmental (block 5: ADI), and cognition (block 6: MoCA). Gender was coded as male (0) or female (1). Assistive device use was coded as no (0) or yes (1) with orthotic devices not considered assistive devices. The order in which predictors were entered was intentionally chosen based on the availability of evidence examining each predictor, with predictors with the most available evidence[19, 22, 25, 26] entered earlier in the regression and predictors that were more exploratory entered later. The change in R^2 was tested for each block entry to determine which group(s) of predictors were significantly ($p < 0.5$) related to percent non-stepping time. All assumptions were tested and met. All statistical analyses were conducted in R (version 4.0.3).[36] Variables that were normally distributed are reported as mean (standard deviation, SD) and those that were not normally distributed are reported as median (interquartile range, IQR).

RESULTS

At the time of analysis, data from 280 participants from the larger clinical trial were available.[24] There was no missing data. Descriptive statistics are displayed in Table 2. The median number of valid recording days was 8 (IQR 5), the mean percentage of time spent in non-stepping behaviors was 81.6% (SD 8.3%) over the valid recording period. For descriptive

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purposes, we also report the median average steps per day (ASPD) of our sample which was 4198.5 (IQR 3178.5).

Results of the sequential linear regression analysis are shown in Table 3. Briefly, the blocks representing physical capacity (block 2, $\Delta R^2 = 0.24$, $p < 0.001$) and psychosocial measures (block 3, $\Delta R^2 = 0.03$, $p = 0.01$) were significant, while blocks representing physical health, physical environment, and cognition were not. Individually, the 6MWT ($\beta = -0.39$, $p < 0.001$), AD use ($\beta = 0.15$, $p = 0.03$), PHQ-9 ($\beta = 0.16$, $p = 0.01$) and BMI ($\beta = 0.11$, $p = 0.04$) were significant predictors (Table 4). These coefficients suggest that poorer physical capacity, using an assistive device, symptoms of depression, and a higher body mass index were associated with greater non-stepping time. The final model was significant ($p<0.001$) and explained 28.5% of the variability in percent non-stepping time.

DISCUSSION

The purpose of this study was to determine what variables are significantly associated with the percentage of time spent in non-stepping behaviors in people with chronic stroke. We hypothesized five different domains, comprised of eight individual predictors, would be significantly related to non-stepping time in people post-stroke. In support of our hypothesis, measures of physical capacity (6MWT, AD use), physical health (BMI) and psychosocial measures (PHQ-9) were significantly related to the percent time spent in non-stepping behaviors. More specifically, lower physical capacity, use of an assistive device, greater depressive symptoms, and a higher BMI were associated with a greater percentage of time spent in non-stepping behaviors. Contrary to our hypothesis, the presence of comorbidities, balance self-efficacy, area deprivation, and cognitive function were not significantly associated with non-stepping behavior. Overall, these results align with past work and add new contributions to understanding non-stepping time in people with stroke.

Our finding that 6MWT, PHQ-9 and BMI were significantly related to non-stepping behavior post stroke corroborates past work demonstrating these variables are important predictors of sedentary time in individuals with stroke.[19, 22, 23, 25, 26, 37] In particular, Hendrickx and colleagues also observed physical capacity (measured by walking speed) and BMI were significantly associated with sedentary time in nine pooled studies in people with stroke.[19] The fact that our work and that of Hendrickx et al, a combined total of 554 people with stroke, found these two predictors were significantly related to sedentary time provides strong evidence that physical capacity and physical health are strongly related to sedentary time in people with stroke. Interestingly, symptoms of depression was not a significant predictor in the model by Hendrickx et al[19]; however, we found higher depressive symptoms were associated with greater time spent in non-stepping behaviors, as has been found by others.[22, 26] This discrepancy may be partly explained by the variability in measures used to quantify depressive symptoms or by the fact the percentage of time spent in non-stepping behaviors was ~12.6% higher in our sample compared to that of Hendrickx and colleagues. However, the high prevalence of sedentary behavior[1-5] and depression[38-40] in people with stroke, coupled with previous reports in larger sample sizes demonstrating a relationship between depression and sedentary behavior in other populations,[41, 42] suggests the relationship between these variables warrants further investigation.

We also observed using an assistive device was associated with greater time spent in non-stepping behaviors post stroke. This may be related to the fact that individuals who require an assistive device for mobility often have lower levels of physical capacity (i.e., greater impairment) compared to those who do not require an assistive device. Indeed, in our sample individuals with stroke who used an assistive device tended to have lower values on the 6MWT (r_{pb} = -0.61, p <0.001). Thus, improving a stroke survivor's physical capacity and working to transition away from the need for these devices may be an effective approach to reducing non-stepping time in individuals with chronic stroke. However, solely targeting physical capacity may not be sufficient for reducing non-stepping time post stroke as other variables, specifically BMI and depressive symptoms (PHQ-9), were also significant in our study. Overall, these findings suggest behavior change programs targeting breaks in sedentary time should be multifaceted and consider the individual's physical capacity (in particular, walking endurance and assistive device use), depressive symptoms and physical health.

Both our results and that of Hendrickx and colleagues[19] found cognition and comorbidities were not significantly associated with sedentary time in individuals with stroke. In addition, we also found balance self-efficacy (ABC) and area deprivation (ADI), which were not explored in the work of Hendrickx et al,[19] were not associated with non-stepping time. This suggests these variables may be less important for some individuals when designing behavior change programs targeting sedentary time.

Contrasting the results of this study with those examining predictors of active time supports the notion that active and sedentary time may be different constructs. For example, past work has shown that balance self-efficacy, specifically the ABC,[28, 43, 44] and area deprivation (ADI)[28, 45] are significantly related to steps/day, a measure of active time, in individuals with stroke. However, both the ABC and ADI were not significant predictors of non-stepping time in the current work. Similarly, several studies in individuals with stroke have observed a non-significant relationship between depressive symptoms and steps/day.[28, 37, 43, 46] However, the PHQ-9 was significantly related to time spent in non-stepping behaviors in the current study. Our previous report in a similar cohort revealed that steps/day was more strongly related to balance self-efficacy than depressive symptoms.[28] The current work has shown the opposite finding in which non-stepping time was more strongly related to depressive symptoms than balance self-efficacy. Collectively, these findings could suggest different psychosocial factors affect active versus sedentary time in people post-stroke which would imply that different psychosocial factors need to be considered in behavior change programs targeting active versus sedentary time. For example, a program targeting increasing steps/day (active time) should consider addressing balance self-efficacy, whereas this may have lower emphasis for a program targeting breaks in sedentary time. As we did not directly test this theory in the current work, this hypothesis will need to be formally tested in future studies. Nonetheless, the results of this work shed new light on the multiple domains that may be important for behavior change programs targeting sedentary time in people with stroke and provides considerations for how this approach may differ from programs targeting active time.

Limitations

There are several limitations to consider when interpreting our results, including the assumptions made when determining what minutes of data would be classified as “wear” or “non-wear”, and subsequently “active” or “non-stepping” time. For example, a minute of 0 steps could be sedentary time (i.e., sitting or lying down), standing time, or non-wear time (e.g., sleep). To address this limitation, we considered past literature measuring sedentary and active time in people with stroke and other populations, past work demonstrating the accuracy of the Fitbit in detecting steps in people with stroke and compared these decisions with expert clinical judgement. In addition, the mean percentage of time spent in non-stepping behaviors in our sample is similar to what has been reported in previous work in stroke,[3, 5, 27, 37, 47] providing additional support that our criterion was reasonable. However, despite these efforts, there remains potential that time deemed “non-stepping” may have truly been “non-wear” time, and vis versa. In a similar vein, we were unable to measure postural alignment and therefore could not discern sitting vs. lying vs. standing time. These limitations led use to define this behavior as “non-stepping time” as opposed to “sedentary time”. An important area for future work will be to develop consensus definitions as to what constitutes sedentary time in people with mobility impairments and efforts are already underway to addressing this.[48] While our model explained additional variance in non-stepping time compared to previous work, 71.5% of the variability remained unexplained. Additional measures may contribute to non-stepping time that were not examined in this work. Similarly, our model is limited by the measures used to quantify the constructs of interest. For example, self-efficacy was captured using a measure specific to balance. However, self-efficacy is multifaceted, and it may be that other aspects of self-efficacy are important for non-stepping time. Another limitation is that this work was cross-sectional, and we therefore do not know the direction of the relationships observed in this study or if improving upon the variables significant in our model will result in positive changes in non-stepping behavior. Future longitudinal studies are needed to confirm the findings from this study.

CONCLUSIONS

In this work, we found that measures of physical capacity, physical health, and psychosocial factors, specifically depressive symptoms, were significantly related to time spent in non-stepping behaviors in people with chronic stroke. This suggests behavior change interventions aimed at reducing time spent in non-stepping behaviors should consider these specific variables, which may differ from interventions aimed at improving active time in people post-stroke. The results of this cross-sectional work provide excellent targets for future longitudinal work and may inform behavior change programs targeting sedentary time in persons with stroke.

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DATA AVAILABILITY: The data set associated with this work is available from the corresponding author upon request.

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503 Table 1. Description of Measures

Domain	Measure	Description
Physical Capacity	6-Minute Walk Test (6MWT)	Participants were instructed to walk as far as possible around a rectangular path for 6 minutes. Greater distance covered on this test reflects greater walking endurance. The 6MWT is a valid and reliable test of walking endurance in individuals with stroke.[49, 50] Measures of physical capacity have been previously shown to be related to both active[29] and sedentary time[19] in individuals with stroke.
	Assistive device (AD) use	During the baseline evaluation, participants were asked if the regularly use an assistive device for walking. Assistive device use was categorized as “yes” or “no” in this analysis.
Psychosocial	Patient Health Questionnaire-9 (PHQ-9)	The PHQ-9 is a screening tool for symptoms of depression. It is a 9-item self-administered questionnaire that asks participants to reflect on how often they have been bothered by specific problems over the past 2 weeks. Participants respond on a Likert scale ranging from “Not at all” to “Nearly every day”. A higher score reflects greater depressive symptoms. Participants who score >5 on this assessment are advised to follow-up with their physician to discuss these issues. The PHQ-9 is a valid and reliable measure of depressive symptoms in

		stroke.[51] Prior work has found a relationship between depressive symptoms and sedentary time in people with stroke.[22, 26]
	Activities Specific Balance Confidence Scale (ABC)	The ABC is a 16-item questionnaire that measures an individual's balance self-efficacy. Participants rate how confident they are performing various tasks on a scale of 0 ("no confidence") to 100 ("complete confidence"). The ratings for each item are averaged to produce a final score that reflects the individual's overall balance self-efficacy. The ABC is a valid and reliable measure in individuals with stroke.[52, 53]
Physical Health	Charlson Comorbidity Index (CCI)	The CCI is a self-report measure of comorbidities that was rendered at the baseline evaluation of the clinical trial. Participants report the presence or absence of specific comorbidities, such as diabetes, myocardial infarction, cancer, and congestive heart failure. Each condition includes a weighting factor based on disease severity. A higher score reflects a greater number and severity of comorbid conditions. The CCI has been shown to predict functional outcomes in individuals with stroke.[54]
	Body mass index (BMI)	BMI was calculated as mass (in kilograms) divided by height in meters squared (kg/m^2). BMI has been previously shown to be

		associated with sedentary time in people with stroke.[19]
Environmental	Area Deprivation Index (ADI)	The ADI is a measure of neighborhood disadvantage and utilizes a percentile ranking from 0 to 100 in which higher scores indicate higher levels of disadvantage.[55] The ADI was obtained using the participant's home address.[55] In our prior work, we found that living in areas of greater deprivation was associated with lower steps/day.[28] However, to the best of our knowledge, this variable has not been explored in the context of sedentary time. The ADI was intentionally selected to represent aspects of the physical and socioeconomic environment.
Cognition	Montreal Cognitive Assessment (MoCA)	The MoCA is a measure of global cognitive impairment. It assesses various domains, such as executive functioning, memory, and attention. Higher scores reflect better global cognitive function. Previous work has shown that the MoCA has acceptable sensitivity and specificity in detecting cognitive impairment in persons with stroke.[56]

Table 2: Participant Characteristics*

Characteristic	Participants
Age (y)	65 (IQR 17)
Time Since Initial Stroke (mo)	23 (IQR 42)
Self-Selected Walking Speed (m/s)	0.71 (SD 0.20)
Body Mass Index (kg/m^2)	30.21 (SD 6.32)
Gender	Male: n = 144 (51.4%) Female: n = 136 (48.6%)
Assistive Device Use	Yes: n = 132 (47.1%) No: n = 148 (52.9%)
6-Minute Walk Test (m)	305.34 (SD 114.31)
Activities Specific Balance Confidence Scale	78.75 (IQR 24.61)
Patient Health Questionnaire-9	3.0 (IQR 6.0)
Charlson Comorbidity Index	3.0 (IQR 2.0)
Area Deprivation Index	31.0 (IQR 28.0)
Montreal Cognitive Assessment	25.0 (IQR 6.0)

*Continuous data presented as mean (standard deviation, SD) for normally distributed variables and median (interquartile range, IQR) for variables not normally distributed.

Table 3: Regression Analysis Predicting Percent Non-Stepping Time

Block	Predictor(s)	R^2	Model *p*	ΔR^2	ΔR^2 *p*
1	Age, Gender, TSIS	0.01	0.51	0.01	0.51
2	6MWT, AD	0.25	< 0.001	0.24	< 0.001
3	ABC, PHQ-9	0.27	< 0.001	0.03	0.01
4	CCI, BMI	0.28	< 0.001	0.01	0.11
5	ADI	0.28	< 0.001	0	0.86
6	MoCA	0.29	< 0.001	0.001	0.54

TSIS = Time Since Initial Stroke; 6MWT = Six Minute Walk Test; AD = Assistive Device use; ABC = Activity Balance Confidence Scale; PHQ-9 = Patient Health Questionnaire; CCI = Charlson-Comorbidity Index; BMI = Body Mass Index; ADI = Area Deprivation Index; MoCA = Montreal Cognitive Assessment

Table 4: Standardized Regression Coefficients of Predictors of Percent Non-Stepping Time

Block	Predictor	*β*	*p*
1	Age	0.07	0.20
	Gender	-0.08	0.14
	TSIS	0.04	0.49
2	6MWT	-0.39	<0.001
	AD	0.15	0.03
3	ABC	-0.01	0.89
	PHQ-9	0.16	0.01
4	CCI	-0.01	0.90
	BMI	0.11	0.04
5	ADI	0.01	0.84
6	MoCA	0.03	0.54

TSIS = Time Since Initial Stroke; 6MWT = Six Minute Walk Test; AD = Assistive Device use; ABC = Activities Specific Balance Confidence Scale; PHQ-9 = Patient Health Questionnaire-9; CCI = Charlson-Comorbidity Index; BMI = Body Mass Index; ADI = Area Deprivation Index; MoCA = Montreal Cognitive Assessment