Disability and Rehabilitation

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/idre20

Intensity of daily physical activity – a key component for improving physical capacity after minor stroke?

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DISABILITY AND REHABILITATION
https://doi.org/10.1080/09638288.2020.1851781

ORIGINAL ARTICLE

Intensity of daily physical activity – a key component for improving physical capacity after minor stroke?

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ABSTRACT

Purpose: Elucidating the complex interactions between physical activity (PA), a multidimensional concept, and physical capacity (PC) may reveal ways to improve rehabilitation interventions. This cross-sectional study aimed to explore which PA dimensions are related to PC in people after minor stroke.

Materials and methods: Community dwelling individuals >6 months after minor stroke were evaluated with a 10-Meter-Walking-Test (10MWT), Timed-Up & Go, and the Mini Balance Evaluation System Test. The following PA outcomes were measured with an Activ8 accelerometer: counts per minute during walking ($CPM_{walking}$; a measure of intensity), number of active bouts (frequency), mean length of active bouts (distribution), and percentage of waking hours in upright positions (duration). Multivariable linear regression models, adjusted for age, sex and BMI, were used to assess the relationships between PC and PA outcomes.

Results: Sixty-nine participants [62.2 ± 9.8 years, 61% male, 20 months post onset (IQR 13.0–53.5)] were included in the analysis. $CPM_{walking}$ was significantly associated to PC in the 10MWT (std. ß = 0.409, $p = 0.002$), whereas other associations between PA and PC were not significant.

Conclusions: The PA dimension *intensity of walking* is significantly associated with PC, and appears to be an important tool for future interventions in rehabilitation after minor stroke.

ARTICLE HISTORY
Received 11 March 2020
Revised 23 October 2020
Accepted 12 November 2020

KEYWORDS
Minor stroke; physical activity; accelerometer; walking speed; physical capacity

➤ IMPLICATIONS FOR REHABILITATION

- It is recommended to express physical activity after minor stroke in multiple dimensions such as intensity, frequency, duration and distribution.
- In particular, intensity of physical activity measured with accelerometer counts is most closely related to physical capacity.
- The findings of this study underline the importance of being physically active beyond a certain intensity.
- In future development of interventions and guidelines that aim to promote daily physical activity, intensity should be taken into account.

Introduction

Worldwide, stroke is one of the leading causes of death and disability [1]. In the Netherlands, around 56% of stroke survivors, the majority diagnosed with "minor stroke", do not participate in a rehabilitation program (whether community based, outpatient or inpatient) because they recuperate relatively quickly and experience almost no visible motor symptoms [2,3].

Although these individuals are all screened for cardiovascular risk factors, reductions in physical capacity (PC) — defined as what an individual can do in a standardized environment [4,5] — may go unnoticed [6,7]. Indeed, significantly reduced levels of PC after minor stroke may be observed more than six months post-onset [8]. This an important finding, as PC is related to functioning, overall health, well-being, and reduction of cardiovascular risk factors for recurrent strokes [9–14].

Optimizing PC is therefore a major target of stroke rehabilitation whether it involves aerobic exercise or strength training [15,16]. Another applied strategy to improve PC is to enhance a person's daily physical activity (PA) by stimulating an active lifestyle [13,17]. PA and PC are intertwined constructs. Research has shown that higher levels of daily PA are correlated to higher PC [17]. Therefore, maintaining or regaining a physically active lifestyle might be an accessible and affordable way to optimize PC [13,18].

PA is an umbrella construct covering multiple dimensions such as frequency, intensity, duration and distribution of PA [19–21].

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Therefore, to evaluate PA sufficiently, PA after minor stroke should be expressed using more than one dimension [19]. However, given this multidimensionality, it is expected that not all PA dimensions will be similarly related to PC outcomes. For example, the review by Wiener et al. [22] indicates that being physically active at a high intensity has a more substantial effect on diverse capacity measures (for example, the 10MWT, Berg Balance Scale, Timed Up & GO) compared to moderate intensity. Further, more prolonged PA bouts (e.g., >10 min) have a more positive effect on PC compared to shorter bouts [23]. In the present study, in accordance with Wiener et al. [22], we considered PC to be a comprehensive term represented by independent validated tests so as to obtain insight into several PC components [4]. Unraveling the complex interactions between PA and PC outcomes will aid in improving the effectiveness of interventions and guidelines [24]. Therefore, this cross-sectional study aimed to explore which dimensions of PA are related to PC in individuals who experienced a minor stroke more than six months prior.

Materials and methods

Participants

Individuals with minor stroke were recruited *via* neurologists and rehabilitation physicians of Radboud University Medical Center Nijmegen, Rijnstate Hospital Arnhem, Reinier de Graaf Gasthuis Delft, and through advertisements in local newspapers in the Netherlands between February 2017 and February 2019. Participants were eligible if they were in the chronic phase (>6 months) after minor stroke. Participants were screened by diagnosis of minor stroke at stroke onset, which was defined in this study as having a unilateral supratentorial transient ischemic attack (TIA) or having motor and/or sensory loss in the contralesional leg at stroke onset, with (near-) complete clinical motor recovery of the paretic leg (Fugl-Meyer Assessment score of the lower extremity ≥24 at the time of inclusion) [25]. Participants were excluded if they were receiving inpatient rehabilitation at the time of inclusion, experiencing other neurological or musculoskeletal problems, having severe cognitive problems (Montreal Cognitive Assessment <24) [26], using psychotropic medication or having persistent unilateral spatial neglect (Behavioral Inattention Test – Star Cancellation Test <44) [27]. This study was approved by the Medical Ethics Committee of the Arnhem-Nijmegen region, and all the participants gave written informed consent prior to the measurements.

Measures

Physical capacity

Participants were invited to Radboud University Medical Center for assessments. PC was assessed by three different tests: comfortable walking speed (10-Meter-Walking-Test, 10MWT), mobility capacity (Timed-Up & Go, TUG) and static and dynamic balance control (Mini Balance Evaluation Systems Test, Mini-BESTest). The 10MWT (duration of walking ten meters at a comfortable speed [4]) was performed three times and the average duration was recorded. The average duration was transformed to walking speed in m/s. Comfortable walking speed is an important aspect of walking capacity and is able to distinguish between different post-stroke ambulation levels [28]. The TUG determines the duration of standing up from a chair, walking three meters, turning around, walking back to the chair and sitting down again [29]. The duration of the TUG was reported. The Mini-BESTest determines balance by assessing tasks such as push and release, standing on toes or one leg, and assesses gait quality during changes in gait speed while avoiding obstacles and turning around [30]. The higher the Mini-BESTest score (maximum of 28) the better the dynamic balance control. PC tests were conducted by two trained assessors. All tests show excellent inter- and intra-rater reliability [31–35].

Physical activity

After the PC assessment, participants wore an Activ8 physical activity monitor at home for seven consecutive days and 24 h per day. The Activ8 is a small (30 × 32 × 10 mm) and light-weight (20 g) triaxial accelerometer that has been validated to continuously measure daily PA in individuals after stroke [36]. The Activ8 was set to record data using a 30-s epoch length. The Activ8 was attached to the front of the thigh of the non-affected leg with Tegaderm™ skin tape. This waterproof attachment allowed participants to swim and shower while wearing the device. In addition, the participants were asked to report waking hours each day in a logbook in order to check whether those hours corresponded with the registration of activity by the Activ8. Since this study focuses on PA, sleep was cut out of the data based on the waking hours reported in the paper logbooks. PA assessments were considered valid if data from at least 10 waking hours per day were available for 5 days.

The output of the Activ8 monitor consists of the time spent in six categories of body postures and movements (lying, sitting, standing, walking, running and cycling) within an epoch length of 30 s. In addition, in each epoch the number of movement counts is calculated for each category, representing the amount of movement within that epoch. By dividing the movement counts by the time spent in a category, the movement intensity can be calculated for each category. Standing, walking, running and cycling were merged into *upright activities*, while the same activities minus standing were classified as *active activities.* If a 30-s epoch showed activity for >24 s (80%), then the epoch was classified as *active.* If at least four sequential active epochs occurred (i.e., ≥2-min period), such a period was classified as an *active bout.* Matlab R2014b was used to process the time and counts of the postures and movements into different outcomes representing four distinct dimensions of PA:

- Counts per minute during walking ($CPM_{walking}$), representing the *intensity* of walking [37]. Walking is the most common and important movement for stroke survivors in daily activities and participation in society [11,38,39].
- The number of active bouts (N $Bout_{active}$), representing the *frequency* of PA.
- The mean length of active bouts (ML $Bout_{active}$), representing the *distribution* of PA, calculated as the sum of the length of all active bouts divided by the number of active bouts [40,41].
- The relative time (% Upright) spent in upright postures and movements, representing the *duration* of PA, calculated by the sum of the duration in upright movements divided by the total waking hours multiplied by 100%.

All outcome measures were averaged per day by dividing by the number of days that contained valid measurements.

Statistical analysis

Descriptive statistics were acquired for all participants, and Kolmogorov–Smirnov tests were used to test for normality of the participant characteristics and the PC and PA measures. The

Table 1. Characteristics of the participants ($n = 69$).

Participant characteristic	
Sex (male/female) (% male)	42/27 (61%)
Age (years)	65.2 (9.8)
Body Mass Index (BMI)	26.1 (23.6 – 28.3)
Type of stroke (ischemic/hemorrhagic/unknown)	62/6/1
Affected body side (left/right) (% left)	36/33 (52%)
Time since stroke (months)	20 (13.0 – 53.5)

Values are mean (SD), median (IQR) or n.

Table 2. Physical capacity (PC) and physical activity (PA) outcomes of participants ($n = 69$).

PC test or PA outcome	
Physical capacity	
10MWT (m/s)	1.3 (0.2)
TUG (seconds)	10.2 (2.0)
Mini-BESTest (score)	24.0 (2.6)
Physical activity	
$CPM_{walking}$	1447.9 (169.9)
N $Bout_{active}$	8.9 (5.0)
ML $Bout_{active}$	6.9 (3.7)
% Upright	34.8 (10.3)

Values are mean (SD); 10MWT: 10-Meter-Walking-Test; TUG: Timed-Up & Go; Mini-BESTest: Mini Balance Evaluation Systems Test; $CPM_{walking}$: counts per minute during walking; N $Bout_{active}$: number of active bouts; ML $Bout_{active}$: mean length of active bouts; % Upright: percentage in upright postures and movements relative to the waking hours. Physical activity outcomes are expressed as mean per waking hours a day. Mean waking hours were 15 h 35 min (SD 1 h 23 min).

results of the 10MWT, TUG, and Mini-BESTest were tested for associations with participant characteristics and PA measures using Pearson's or Spearman's correlation coefficients. The association of PC with the dichotomous variable sex was assessed using a *t*-test or Mann–Whitney *U* test. Stepwise multivariable linear regression analyses were conducted, with the 10MWT, TUG and Mini-BESTest results as dependent variables and PA outcomes ($CPM_{walking}$, N $Bout_{active}$, ML $Bout_{active}$, % Upright) as independent variables, adjusted for potential confounders (age, sex and BMI). With seven independent variables in each model, we aimed to include at least 70 participants [42]. Assumptions for linear regression were checked: homoscedasticity was tested by plotting the residuals versus the fitted values, presence of multicollinearity was determined by a variance inflation factor (VIF) larger than 3, and influential points were inspected with Cook's distance. To correct for multiple testing in the regression models, the significance level was set at $\alpha < 0.05/3 = 0.017$. For the *t*-test, Mann–Whitney U test and correlations, a significance level of $\alpha < 0.05$ was used. All analyses were performed using Rstudio version 1.1.456.

Results

Seventy-four patients were included in this study. Five participants were lost to follow-up, because the Activ8 was not returned ($n = 1$), there was an invalid number of measurement days ($n = 1$) or there were technical problems with the Activ8 ($n = 3$). Therefore, 69 patients were included in the analysis. Patient characteristics are shown in Table 1. The majority of the participants were male (61%). The mean age of all participants was 65.2 (SD 9.8) years, and age was significantly different between males [mean (SD): 67.0 (9.1)] and females [mean (SD): 62.3 (10.2)], $p = 0.047$. All other patient characteristics were not significantly different between males and females. The median time since occurrence of the minor stroke event was 20 months (IQR 13.0 – 53.5) and the majority of the participants had sustained an ischemic stroke.

Table 3. Correlation coefficients of physical capacity tests (10MWT, TUG, Mini-BESTest) vs. participant characteristics and physical activity outcomes.

	10MWT	TUG	Mini-BESTest
Characteristics			
Age	0.440**	0.369**	−0.488**
BMI	−0.090	0.175	−0.253*
Physical activity			
$CPM_{walking}$	0.428**	−0.160	0.155
N $Bout_{active}$	−0.170	−0.219	0.280*
ML $Bout_{active}$	−0.179	−0.108	−0.019
% Upright	−0.073	−0.188	0.042

*$p < 0.05$; **$p < 0.01$; 10MWT: 10-Meter-Walking-Test; TUG: Timed-Up & Go; Mini-BESTest: Mini Balance Evaluation Systems Test; $CPM_{walking}$: counts per minute during walking; N $Bout_{active}$: number of active bouts; ML $Bout_{active}$: mean length of active bouts; % Upright: percentage in upright postures and movements relative to the waking hours.

Table 4. Multivariable linear regression models representing the relation between physical capacity tests and physical activity outcomes.

	R^2	ß (SE)	95%CI	Std. ß	*p* Value
10MWT	0.331				
$CPM_{walking}$		0.001 (0.003)	[−0.000, −0.001]	0.409	0.002*
N $Bout_{active}$		−0.011 (0.007)	[−0.025, 0.002]	−0.261	0.107
ML $Bout_{active}$		0.002 (0.007)	[−0.017, 0.015]	0.030	0.794
% Upright		0.002 (0.003)	[−0.004, 0.001]	0.099	0.475
TUG	0.205				
$CPM_{walking}$		−0.002 (0.002)	[−0.005, 0.001]	−0.183	0.205
N $Bout_{active}$		0.049 (0.071)	[−0.092, 0.190]	0.122	0.488
ML $Bout_{active}$		0.009 (0.069)	[−0.129, 0.147]	0.017	0.895
% Upright		−0.016 (0.029)	[−0.073, 0.045]	−0.074	0.679
Mini-BESTest	0.293				
$CPM_{walking}$		0.001 (0.036)	[−0.003, 0.005]	0.035	0.796
N $Bout_{active}$		0.018 (0.085)	[−0.152, 0.188]	0.035	0.843
ML $Bout_{active}$		−0.004 (0.083)	[−0.170, 0.162]	−0.003	0.960
% Upright		−0.035 (0.036)	[−0.108, 0.038]	−0.140	0.339

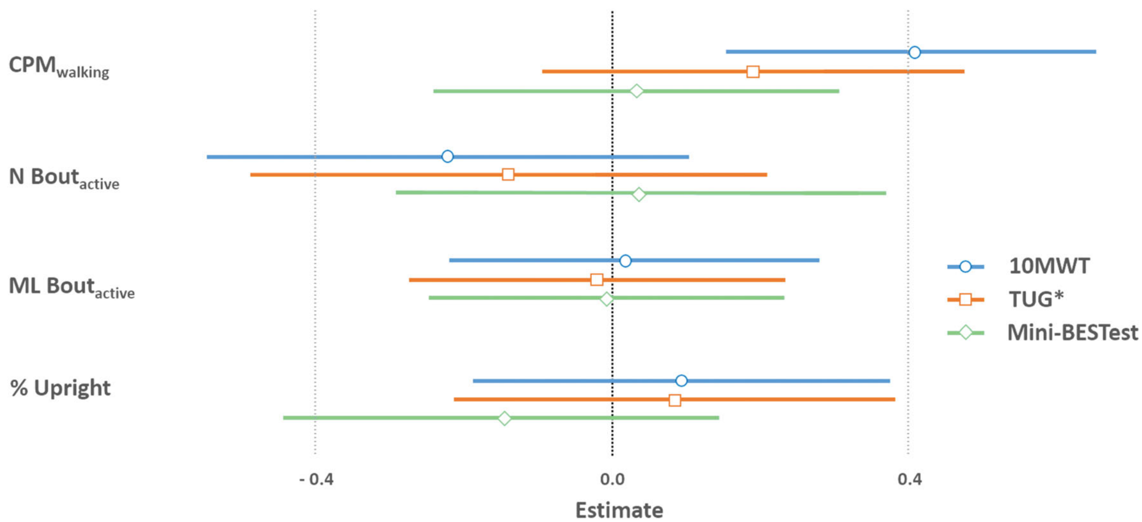
All models were adjusted for age, sex and BMI. * = $p < 0.017$; 10MWT: 10-Meter-Walking-Test; TUG: Timed-Up & Go; Mini-BESTest: Mini Balance Evaluation Systems Test; $CPM_{walking}$: counts per minute during walking; N $Bout_{active}$: number of active bouts; ML $Bout_{active}$: mean length of active bouts; % Upright: percentage in upright postures and movements relative to the waking hours.

Table 2 presents the PC (10MWT, TUG and Mini-BESTest) and PA outcomes ($CPM_{walking}$, N $Bout_{active}$, ML $Bout_{active}$ and % Upright) of the participants. The mean number of waking hours measured with the Activ8 accelerometer was 15 h 35 min (SD 1 h 23 min) per day.

Table 3 shows the correlation coefficients between the PC tests (10MWT, TUG and Mini-BESTest), participant characteristics (age, BMI) and the four different PA outcomes ($CPM_{walking}$, N $Bout_{active}$, ML $Bout_{active}$, % Upright). All correlation coefficients were low to moderate ($r < 0.5$).

Table 4 shows the results of the multivariable linear regression models with the three PC tests as dependent variables and the PA outcomes as independent variables. All models were adjusted for age, sex and BMI. The only PA outcome that correlated significantly to PC was $CPM_{walking}$ in the 10MWT model (std. $\beta = 0.409$, $p = 0.002$). The other PA outcomes did not show significant associations with the PC tests.

Figure 1 presents a visual summary of the standardized estimates of the PA outcomes in the three PC regression models. To improve visual comparison with the other outcomes, the scores of the TUG were inverted, so that the direction of all outcomes is the same.



*NOTE: in order to compare the direction of the association between physical activity and physical capacity, the scores of the TUG were inverted. Circles, squares and deltoids are standardized estimates with 95%CI. 10MWT: 10-Meter-Walking-Test; TUG: Timed-Up & Go; Mini-BESTest: Mini Balance Evaluation Systems Test; CPM $_{walking}$: counts per minute during walking; NBout$_{active}$: number of active bouts; ML Bout$_{active}$: mean length of active bouts; % Upright: percentage in upright postures and movements relative to the waking hours.

Figure 1. Summary of standardized estimates with 95% confidence intervals of the association between multiple physical activity outcomes and physical capacity tests.

Discussion

This study examined relationships between PA and PC, more than six months after minor stroke. The intensity of daily walking was significantly associated with PC, as determined by the 10MWT. No other PA dimension (frequency, duration or distribution) was related to any of the PC outcomes (10MWT, TUG, Mini-BESTest).

Our findings are in line with those of earlier studies in which PA intensity was correlated to PC. Both Mudge et al. [43] and van de Port et al. [44] also found a moderate to strong relationship between measures of PA intensity during walking and comfortable walking speed in more-severe stroke patients. However, they did not examine multiple outcomes of PA in relationship to walking tests concurrently, thus limiting further comparison with our results. Wolff-Hughes et al. [45] found a relationship between movement intensity and cardiometabolic biomarkers, which was stronger than the relationship between the distribution outcome *accumulation of PA in long bouts* and the same biomarkers. Therefore, we suggest including a measure of intensity when evaluating PA, to avoid missing important information about a person's PA that might signify a risk for health issues.

Our finding that intensity showed the strongest association with PC might be explained by the fact that the 10MWT and the intensity outcome $CPM_{walking}$ are indicators of walking speed [37]. $CPM_{walking}$ has a strong conceptual or theoretical linkage with walking speed as measured during the 10MWT [46]. The different environments between the 10MWT and $CPM_{walking}$ during free-living conditions do not seem to play a significant role. The link between daily CPM $_{walking}$ is weaker with the TUG and the Mini-BESTest. They require more complex coordination and control skills due to transitions between postures and movements, whereas the 10MWT involves only walking.

The TUG and the Mini-BESTest show weak or nearly absent associations with PA frequency, distribution and duration. Possibly, the more complex tasks required during these tests are not representative of the activities performed in daily life, although in the latter, people are also confronted by diverse challenges [47]. Another explanation for the absence of association might be related to the type of PA outcomes measured in our study. For example, if rising time from a chair was quantified in daily life, relationships with TUG may have been found. This supports the importance of measuring not only each person's capacity with standardized tests, but also the actual performance in daily life, and disentangling the relationships between the different outcomes of these domains.

Although we found a statistically significant and strong association between the self-selected walking speed during the 10MWT and daily life accelerometer counts during walking ($CPM_{walking}$), the explained variance of this regression model was low. This could be because walking in a free-living environment incorporates a broader range of walking activities compared to the self-selected walking speed on a flat surface in a straight line during the 10MWT, as shown by previous research [43]. However, self-selected walking speed is a relevant measure in individuals after minor stroke since it is associated with several health outcomes, including functional decline, mobility disability, and clinically relevant changes in quality of life [48,49]. Future research should focus on exploring the causal relationships between walking capacity tests and intensity of walking in daily life as well as related health outcomes in minor stroke patients. Other PC models also showed a low explained variance and wide confidence intervals of the standardized estimates. This suggests high intra-individual variability in the association between daily life PA and PC. One possible explanation is that other factors involved in community PA, such as the physical and social environment or levels of mental and social functioning, contribute to variability between individuals [17,50].

Nevertheless, our findings suggest the importance of performing activities beyond a certain intensity, speed, or energy expenditure threshold when one aims to improve PC. Especially in minor stroke cases, secondary prevention is essential, and targeting the intensity of PA seems opportune, since this parameter is lowered compared to healthy peers [8,51]. Moreover, previous studies showed that when persons who suffered from a stroke exercise at high intensities, their quality of life improves and the likelihood of stroke recurrence is reduced [39,52,53]. Future studies should seek to determine the intensity threshold that improves PC most effectively, so it can be used to set targets in interventions.

Some limitations need to be addressed. First, the cross-sectional design of this study limits conclusions on causal inference. Second, although PA operationalization and data processing were developed carefully, our results may still depend on the selection of PA outcomes that were included. However, we chose distinct and uncorrelated measures representing theoretically different dimensions of PA. Third, previous studies often used other types of accelerometers to measure objective outcomes of PA of stroke patients, such as the Stepwatch Activity Monitor or the ActivPAL [19]. The use of those different accelerometers might limit comparisons to our results, obtained with the Activ8 accelerometer. We note that the Activ8 has been shown to provide relevant and valid information on postures and movement to map the daily PA of stroke patients [36]. Lastly, the generalizability of our findings is limited by the relatively young age of our study sample and the wide range of times after stroke occurrence.

In conclusion, the present study provides insight into the relationship between multidimensional PA and PC in individuals after minor stroke. The intensity of walking, measured by accelerometer counts during walking, appears to be a useful tool to increase the effectiveness of interventions that aim to improve PC after minor stroke. Future studies could evaluate if and how augmenting PA intensity leads to increased PC, ultimately to improve overall health and quality of life.

Acknowledgements

The authors thank Sanne Beurskens for her help with data collection and analysis.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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