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Time Dependency of Walking Classification in Stroke
Boudewijn Kollen, Gert Kwakkel and Eline Lindeman
PHYS THER. 2006; 86:618-625.

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Time Dependency of Walking Classification in Stroke

**Background and Purpose.** To facilitate optimal stroke rehabilitation, valid interpretation of observed functional recovery is required. The purpose of this study was to examine the longitudinal relationship between comfortable walking speed and Functional Ambulation Categories (FAC) scores for physically independent gait. **Subjects.** This study was a prospective cohort study with 73 subjects who were severely affected by acute stroke. **Methods.** Functional Ambulation Categories classification and walking speed were measured between weeks 4 and 26 after stroke. The responsiveness of walking speed measurements for detecting clinically important speed changes was determined, and the longitudinal association between walking speed and FAC scores and its time dependency were established. This relationship subsequently was scrutinized for possible speed changes occurring within specific FAC scores. **Results.** Responsiveness ratios exceeded the smallest detectable differences. Random coefficient analysis demonstrated a significant between- and within-subject coefficient and a significant negative interaction between timing of measurements and FAC scores. Paired Student t tests revealed mostly significant pretest-posttest differences in walking speeds, and all kappa values for pretest-posttest FAC scores were significant. **Discussion and Conclusion.** Walking speed measurements are sensitive for detecting clinically important changes. Functional Ambulation Categories scores are dependent on the timing of comfortable walking speed measurements after stroke. Moreover, there are indications that, in this relationship, repeated FAC appraisals are not only based on steady walking speeds, but that the walking speeds related to a specific FAC appraisal also change and, over time, may shift gradually from higher to lower speeds. [Kollen B, Kwakkel G, Lindeman E. Time dependency of walking classification in stroke. Phys Ther. 2006;86:618–625.]

**Key Words:** Cerebrovascular disorders, Gait, Measurement, Stroke recovery.

*Boudewijn Kollen, Gert Kwakkel, Eline Lindeman*
 Stoke is the leading cause of disability among adults and frequently results in impaired mobility. Regaining the ability to walk is the goal most frequently stated by patients with hemiparesis in stroke rehabilitation. The expected level of walking has been found to be reliable and valid in classifying hemiplegic gait. However, home and community mobility present additional challenges to walking ability, as independence requires safety of mobility.

Independent gait is considered a primary goal in stroke rehabilitation. What constitutes independent gait often is based on Functional Ambulation Categories (FAC) classification. The FAC instrument is designed to provide information on the level of physical support needed by subjects in order to ambulate safely. This instrument has been found to be reliable and valid in classifying hemiplegic gait.

Walking speed has been established as an important predictor of walking capability along a continuum from limited household ambulation to unlimited community ambulation. Additionally, walking speed is a simple but highly reliable and responsive parameter for gait. Reliability has been established for test-retest and between-observer measurements. The high correlation coefficients found for the relationship between speed measurements and time-distance parameters, such as cadence, cycle time, stance time, swing time, stride length, step length, and walking speed as well as ambulatory performance, support the validity of speed measurements. Moreover, gait speed correlates strongly with other parameters, such as balance, use of walking aids, and number of falls and ADL function in elderly people.

Findings from longitudinal studies with repeated measurements over time indicate that recovery from neurological impairment and disability shows a nonlinear pattern as a function of time. These studies also indicate that clinical determinants show considerable improvement in the early stages after stroke onset. As a consequence, differences in the timing of measurements could confound predictive relationships in cross-sectional research. Therefore, information obtained from repeated measurements over time after stroke and knowledge of the stability of an instrument are required for better understanding and interpretation of observed changes.

The concept of stability of a measurement instrument is closely related to responsiveness and minimally important clinical change. Responsiveness often is defined as the capacity of an instrument to detect a real meaningful clinical change in patient performance. It consists of a signal-to-noise ratio. As a consequence, increasing measurement error necessitates observing larger pretest-posttest changes. However, a single agreed-upon standard criterion of change is lacking in clinical measurements. Therefore, the term “minimal clinically important difference” (MCID) was introduced. Minimal clinically important differences are derived mainly from clinical judgments based on the measurement properties of an instrument, the patient population, and the magnitude of change considered “minimally important” by the practitioner. Although repeated measurements with a simple timed walking test have been qualified as a responsive method for measuring changes in walking performance over time in the general population of people with stroke, responsiveness has not been established for people with severe motor dysfunction. Therefore, the first objective in the present study was to demonstrate the adequate responsiveness of repeated walking speed measurements for detecting changes over time.

Because the effects of longitudinal measurements on the relationship between walking speed and FAC scores have not been established, the second objective of this study was to demonstrate the significance of the relationship between gait speed and independent gait capability over...
time. The third objective was to study the course of these walking speeds over time and identify possible speed changes that may occur within specific FAC scores. On the basis of these objectives, the following questions were addressed in the study: (1) Are repeated comfortable walking speed measurements sensitive enough to detect poststroke changes in physically independent gait in people who are severely affected by stroke? (2) Is the relationship between FAC scores for independent gait and comfortable walking speed measurements dependent on time after stroke? and (3) Are FAC appraisals subject to changing walking speeds over time after stroke?

Method

Design and Procedures
This prospective cohort study was part of a randomized clinical trial conducted to study the effects of intensity of rehabilitation on stroke outcome. In this study, 101 subjects with stroke participated; their mean age was 65 years (SD=12.0). Subjects were included when they met the following criteria: aged 30 to 80 years; had an ischemic, first-ever stroke involving the territory of the middle or anterior cerebral artery, as revealed by computed tomography or magnetic resonance imaging; displayed an inability to walk at first assessment; revealed no complicating medical history, such as cardiac, pulmonary, or orthopedic disorders; had no severe deficits in communication (a speech therapist assessed the ability to communicate and accepted a cutoff point of the 50th percentile corrected for age on the Dutch Foundation Aphasia test) or severe deficits in memory and understanding (the Mini-Mental State Examination was used to assess orientation in time and place; only subjects with a score of 24 points or more were included in the trial); provided written or verbal informed consent; and demonstrated sufficient motivation to participate (yes or no, at the discretion of the observer [GK]). By adhering to these inclusion criteria, we obtained a relatively homogeneous study population that initially demonstrated severe motor dysfunction. We did not find any differential treatment effects attributable to systematic therapeutic interventions at 6 months. Details about design and outcome are published elsewhere.

Measurements
Independent gait was based on FAC measurements. This instrument distinguishes among 6 levels ranging from dependence to independence (Tab. 2). For the purpose of this study, FAC scores of 3 to 5 were used because these scores do not involve physical assistance from a therapist, which could bias registered walking speed. The first measurement of gait speed was taken as soon as subjects were able to walk independently under supervision without any physical assistance from the therapist. This criterion corresponds to an FAC score of 3. An FAC score of 4 represents unsupervised safe independence in walking on level ground, and an FAC score of 5 denotes safe ambulation anywhere, including stairs (Tab. 2). Walking devices were allowed to be used during the measurements, with the exception of a rollator or walker, because their use may bias the outcome of measurements by offering too much support to the subject. Thus, subjects who scored 0, 1, or 2 on the FAC classification or who were dependent on a rollator or walker were excluded from the analysis.

Measurements were started within 14 days of stroke onset for all subjects and were obtained weekly up to 10 weeks, once every 2 weeks up to 20 weeks, and once at 26 weeks after onset. All walking speed measurements were obtained by one observer (GK), and FAC scores were retrieved by the same observer either by information obtained from the therapist or, if necessary, from perusing subject charts. Each subject was classified for walking ability by a therapist who received instruction without any physical assistance from the therapist.

### Table 1.
Subject Characteristics Measured in Week 2 After Stroke

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of subjects (women/men)</td>
<td>73 (29/44)</td>
</tr>
<tr>
<td>Age, y, X (SD)</td>
<td>64.8 (10.5)</td>
</tr>
<tr>
<td>MMSE score (0–30), X (SD)</td>
<td>26.7 (2.3)</td>
</tr>
<tr>
<td>Stroke hemisphere (left/right), no. of subjects</td>
<td>31/42</td>
</tr>
<tr>
<td>Type of stroke, no. of subjects</td>
<td>36</td>
</tr>
<tr>
<td>TACI (no/yes)</td>
<td>30</td>
</tr>
<tr>
<td>PACI (no/yes)</td>
<td>7</td>
</tr>
<tr>
<td>LACI (no/yes)</td>
<td>1.6–6.8, X (SD)</td>
</tr>
<tr>
<td>GCS score (0–15), X (SD)</td>
<td>14.8 (0.89)</td>
</tr>
<tr>
<td>Cognitive impairments (% of subjects)</td>
<td>44.4</td>
</tr>
<tr>
<td>Visual inattention (no/yes)</td>
<td>25.0</td>
</tr>
<tr>
<td>Hemianopia (no/yes)</td>
<td>17.8</td>
</tr>
<tr>
<td>Visual gaze deficit (no/yes)</td>
<td>8.2 (2.8)</td>
</tr>
<tr>
<td>No. of days between CVA and first measurement, X (SD)</td>
<td>35.4 (28.3)</td>
</tr>
<tr>
<td>MI for lower extremity (0–100), X (SD)</td>
<td>65.13 (26.26)</td>
</tr>
<tr>
<td>TCT score (0–200), X (SD)</td>
<td>2.66 (1.37)</td>
</tr>
<tr>
<td>Brunström score (1–6), X (SD)</td>
<td>0.04 (0.15)</td>
</tr>
<tr>
<td>BI (0–20), X (SD)</td>
<td>7.21 (3.46)</td>
</tr>
<tr>
<td>FAC score (0–5), X (SD)</td>
<td>0.94 (0.98)</td>
</tr>
</tbody>
</table>

MMSE=Mini-Mental State Examination, OPS=Orpington Prognostic Scale, GCS=Glasgow Coma Scale, CVA=cerebrovascular accident, MI=Motricity Index, TCT=Trunk Control Test, BI=Barthel Index, FAC=Functional Ambulation Categories.

and training before the implementation of the study to ensure the standardization of FAC appraisals.

Gait speed was studied at comfortable walking speeds by use of a standard approach for assessing gait performance.\textsuperscript{5,16,24} In order to reduce measurement error, the mean of 3 repeated walking speed measurements was calculated.\textsuperscript{24,31} During each session, the subjects walked 10 m at a comfortable pace. A digital stopwatch with a precision of 1/100th of a second was used for the registration of time. Between the 10-m walking tests, subjects rested for about 1 minute. Registered speed subsequently was converted to meters per second by dividing the distance walked by the time required. No encouragements were allowed to facilitate performance during a walking session.\textsuperscript{24}

Data Analysis

We elected to conduct a statistical analysis on the data collected within the period between weeks 4 and 26 after stroke, as this represents the time window in which almost all physically independent walking change occurred in our study population. This change is required to determine the presence of time dependency of measurements.

For the first research question, the responsiveness of walking speed measurements was investigated by calculating the responsiveness ratio (RR). The RR is an effect size and is the ratio of the mean change score for subjects who clinically improved or deteriorated (ie, signal) to the variability for subjects who did not improve or deteriorate (ie, noise).\textsuperscript{27} In order to determine improvement or deterioration in walking speed, we used an MCID of 10\% as the minimal acceptable clinical change.\textsuperscript{32,33} Therefore, the responsiveness of walking speed measurements was calculated as the ratio of the mean change score for subjects in the $\geq$10\% scores group to the standard deviation for subjects in the group with <10\% scores (SD$_{change \ group}$). In order for this measurement instrument to be responsive for detecting change over time, the signal should exceed the smallest detectable difference (or the smallest real difference) that corresponds to 1.96 times the noise level (2 times the standard deviation).

For the second research question, random coefficient analysis was used to determine the relationship between walking speed measurements and FAC scores over time and the interaction of FAC appraisals with the timing of measurements after stroke (SPSS version 12.0*). This statistical method generates a within- and between-subject regression coefficient for all measurements involved by analyzing cross-sectional and longitudinal treatment and time effects simultaneously while correcting for the correlated observations within subjects over time and allowing for regression coefficients to differ between subjects.\textsuperscript{34} As time constitutes an independent covariate in such a regression model, this statistical method enables longitudinal analysis of unequally spaced time points of measurements. Interaction (or effect modification) occurs when the association of an independent variable (ie, FAC) with outcome (ie, comfortable walking speed) is changed by the value of a third variable (ie, time of measurement). In a multivariate regression model, interaction can be demonstrated by incorporating a product term (ie, time of measurement $\times$ FAC). A statistically significant product term indicates dependency in such a relationship; that is, the observed association between the outcome and the determinant is modified by the third variable.\textsuperscript{35} Finally, in random coefficient analysis, missing data are presumed to be missing at random.

For the third research question, paired Student $t$ tests were conducted to demonstrate significance in pretest-posttest differences in mean walking speeds, and the Cohen kappa statistic was used to test for agreement between FAC readings from 2 consecutive measure-

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
\textbf{Score} & \textbf{Category} & \textbf{Guidance} \\
\hline
0 & Nonfunctional (unable) & Person cannot walk or requires help of 2 or more people \\
1 & Dependent, level 2 & Person requires firm, continuous support from 1 person to help with carrying weight and with balance \\
2 & Dependent, level 1 & Person needs continuous or intermittent support from 1 person to help with balance or coordination \\
3 & Dependent on supervision & Person requires verbal supervision or stand-by help from 1 person without physical contact \\
4 & Independent on level ground & Person can walk independently on level ground but requires help on stairs, slopes, or uneven surfaces \\
5 & Independent & Person can walk independently anywhere \\
\hline
\end{tabular}
\caption{Functional Ambulation Categories Classification}
\end{table}
ments after stroke (SPSS version 12.0). All hypotheses were tested in a 2-tailed fashion with a $P < .05$ level of significance.

**Results**

The mean interval between stroke onset and first unassisted walk was 4.8 weeks (SD = 2.9 weeks). None of the subjects with stroke in our study were able to walk unassisted during week 1 after stroke onset. At week 2, the highest level of independent gait achieved was supervised walking, and at week 3, the highest level was unassisted walking on level ground. Because not all 101 subjects from the original study progressed to unassisted walking at some point in time and the number of those who did increased gradually during the time after stroke, ultimately a maximum of 73 subjects were selected for walking speed measurements. The number of subjects who were classified as physically independent walkers at any time point of measurement (with the exception of week 2) increased gradually from 25 in week 4 to 73 in week 26 (Tab. 3). The mean comfortable speed measurements ranged from 0.19 to 1.11 m/s.

**Research Question 1**

Responsiveness ratios based on a 10% MCID exceeded the smallest detectable difference and ranged from 4.36 to 17.70 (Tab. 4).

**Research Question 2**

Random coefficient analysis of all poststroke measurements produced a significant between- and within-subject regression coefficient of 0.113 (confidence interval [CI] = 0.079–0.147, $P = .000$, count = 664) but also demonstrated a significant negative interaction between the timing of measurements and FAC scores ($b = -0.003$, CI = -0.005 to -0.001, $P = .010$).

**Research Question 3**

Paired Student $t$ tests revealed mostly (83%) significant pretest-posttest differences in walking speeds, and kappa

<table>
<thead>
<tr>
<th>FAC Score</th>
<th>Measurement</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>26</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>No. of subjects</td>
<td>11</td>
<td>14</td>
<td>14</td>
<td>17</td>
<td>23</td>
<td>23</td>
<td>22</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>16</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Walking speed (m/s)</td>
<td>0.45</td>
<td>0.43</td>
<td>0.37</td>
<td>0.45</td>
<td>0.33</td>
<td>0.39</td>
<td>0.38</td>
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<td>0.33</td>
<td>0.29</td>
<td>0.30</td>
<td>0.30</td>
<td>0.19</td>
</tr>
<tr>
<td>4</td>
<td>No. of subjects</td>
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<td>10</td>
<td>9</td>
<td>8</td>
<td>12</td>
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<td>13</td>
<td>15</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Walking speed (m/s)</td>
<td>0.73</td>
<td>0.90</td>
<td>0.80</td>
<td>0.63</td>
<td>0.65</td>
<td>0.64</td>
<td>0.58</td>
<td>0.57</td>
<td>0.50</td>
<td>0.50</td>
<td>0.49</td>
<td>0.48</td>
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<tr>
<td>5</td>
<td>No. of subjects</td>
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<td>7</td>
<td>11</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>18</td>
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<td>24</td>
<td>27</td>
<td>27</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Walking speed (m/s)</td>
<td>1.08</td>
<td>0.92</td>
<td>1.04</td>
<td>1.04</td>
<td>1.06</td>
<td>1.02</td>
<td>1.11</td>
<td>1.07</td>
<td>1.06</td>
<td>1.04</td>
<td>1.00</td>
<td>1.02</td>
<td>0.92</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value at the following weeks after stroke:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4–5</td>
</tr>
<tr>
<td>Mean change score for subjects with scores of ≥10%</td>
<td>.21</td>
</tr>
<tr>
<td>SD_change group for subjects with scores of &lt;10%</td>
<td>.02</td>
</tr>
<tr>
<td>Responsiveness ratio</td>
<td>10.21</td>
</tr>
<tr>
<td>$t$ test for speed difference, $X$</td>
<td>- .06</td>
</tr>
<tr>
<td>$P$</td>
<td>.00</td>
</tr>
<tr>
<td>Kappa value for FAC agreement</td>
<td>.57</td>
</tr>
<tr>
<td>$P$</td>
<td>.00</td>
</tr>
</tbody>
</table>
values for pretest-posttest FAC scores ranged from .40 to .90 and were all significant for subsequent measurements over time after stroke (Tab. 4). The Figure shows this relationship over time along with CIs for mean walking speeds in relation to these specific FAC scores.

Discussion
This longitudinal study showed that comfortable walking speed measurements are sensitive enough to detect relatively minor poststroke changes in physically independent gait on the basis of FAC classification in people with a severe middle or anterior cerebral artery stroke. In addition, the results showed that the classification of walking ability on the basis of FAC scores is dependent on the timing of poststroke comfortable walking speed measurements. Moreover, there are indications that, in this relationship, repeated FAC appraisals are not only based on steady walking speeds, but that the walking speeds related to a specific FAC appraisal also change and, over time, may shift gradually from higher to lower speeds.

All RRs exceeded the smallest detectable difference in our subjects with severe stroke. In particular, within the period from weeks 4 to 7 after stroke, high RRs were observed for comfortable walking speeds, suggesting that relatively most relevant clinical walking speed changes took place within this period. These findings indicated that walking speed measurements were sensitive for detecting clinically important changes and were suitable for demonstrating pretest-posttest time-related poststroke changes in comfortable walking speeds in our sample.

Over the entire study period, a significant association was demonstrated between walking speeds and FAC scores for physically independent gait. However, this relationship was dependent on the timing of measurements and became weaker as poststroke time passed (.113 minus .003 for each consecutive measurement).

On the basis of paired t tests, pretest walking speeds were mostly found to be different from posttest walking speeds despite narrow measurement intervals. These differences coincided with similar pretest-posttest FAC appraisals, as the kappa statistic agreement between FAC scores was mostly high and consistent throughout the testing period. Although FAC pretest-posttest measurements, especially those obtained weekly after stroke, were spaced closely over time and, as a result, may have been subject to recall bias, the emerging overall pattern was one of changing walking speeds coupled with highly correlated pretest-posttest FAC appraisals.

These findings suggest that repeated FAC appraisals are not only based on steady walking speeds, but that the walking speeds related to a specific FAC appraisal also change and, over time, may shift gradually from higher to lower speeds (Figure). For example, mean walking speeds related to an FAC score of 3 declined from 0.45 m/s in week 4 and 0.38 m/s in week 10 to 0.19 m/s in week 26. This observation indicates that a critical appraisal of the outcome of repeated measurements remains important, as unexpected phenomena (such as a shift) may interact with clinimetrically sound (ie, reproducible, valid, and responsive) instruments and, as a consequence, may affect clinical decision making.

The underlying biological mechanism responsible for the shift in the classification of walking ability on the basis of FAC scores in our population is unknown and warrants further investigation. However, it is very likely that a therapist’s perception of safe independent walking gradually changes over time because of a developing familiarity with the walking skills of a patient. This suggests that the therapist most familiar with a particular patient should conduct FAC appraisals for that patient. When doing so is not feasible, adequate transfer of information to the replacing therapist becomes important.
Another possible explanation is that FAC appraisals and measurements of gait speed may not be equally sensitive to detecting time-dependent changes after stroke. Recent studies showed that FAC-based independent gait is associated more with standing balance control, in particular generated from the nonparetic side, than it is with paresis and spasticity on the paretic side. However, gait speed is relatively more dependent on the gradual development of muscle strength and spasticity-induced stiffness on the paretic side.

Finally, one may hypothesize that the use of walking devices, which usually are issued in the subacute phase to people with more severe hemiplegic strokes and with a relatively slower walking pace, affects balance control and thus FAC scores at the expense of speed.

In quality-of-life research, a similar changing relationship is observed. This phenomenon is known as response shift, which can be defined as a change in the meaning of a respondent’s self-evaluation of a target construct as a result of a change in the respondent’s internal standards of measurement (“scale recalibration” in psychometric terms), a change in the respondent’s values (reprioritization), or a redefinition of the target construct (reconceptualization). The appraisal of symptoms in a longitudinal design is based on 2 assumptions. First, observers have an internalized standard of measurement for symptoms and, second, an observer’s internalized standard of measurement of the dimension being used will not change over time. Whereas in quality-of-life questionnaires self-report symptoms are evaluated on the basis of changes in the construct within the same person, in the present study, changes in the observer’s construct were catalyzed by an objective parameter (ie, walking speed) from another person. This finding shows that changes in appraisals can be based on objective measures.

However, whether these speed changes in FAC appraisals constitute a response shift is uncertain. Response shift is a phenomenon reported as a source of contamination of self-report measures in educational training interventions and quality-of-life studies. To date, such a change in the assessment of gait has not been reported. However, practitioners should be aware of a possible shift-induced bias in appraisal-related instruments. Because response shift in a placebo-controlled trial is absent in the placebo group, the outcome based on such instruments may be biased. In light of response shift and appraisal, Schwartz and Rapkin called for a reconsideration of the psychometrics of quality-of-life assessments.

Future research may be directed toward determining whether the mechanisms in the observed shift in FAC scores are similar to those reported in quality-of-life studies. The first step may be to implement the so-called “thentest” procedure in FAC appraisals. This measure requires the observer to complete 2 posttests. The first test indicates the actual score, and the second test requests a renewed judgment on the observer’s pretest score. It is hypothesized that posttest and thentest measures will be based on the same internal standard of measurement and will provide an indication of the actual change that occurred. The mean difference between pretest and thentest scores indicates the magnitude and direction of the effect caused by the shift. This method also allows for the estimation of recall bias.

Conclusion
The results of this study showed that repeated comfortable walking speed measurements are sensitive enough to detect changes in physically independent gait in people who are severely affected by stroke. Functional Ambulation Categories scores were found to be dependent on the timing of comfortable walking speed measurements after stroke. In addition, there are indications that, in this relationship, repeated FAC appraisals are not only based on steady walking speeds, but that the walking speeds related to a specific FAC appraisal change and, over time, may shift gradually from higher to lower speeds.

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