Recovery of Gait After Short-Stay Total Hip Arthroplasty

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Objective: To describe recovery of gait after total hip arthroplasty (THA) based on the assessment of spatiotemporal gait parameters determined with an ambulatory system.

Design: A 6-month inception cohort study.

Setting: Inpatient and outpatient setting in an academic hospital.

Participants: Sixty-three patients participating in a short-stay program for THA.

Intervention: Primary unilateral THA.

Main Outcome Measures: Walking speed, step length, step duration, and variability coefficient assessed at different walking speeds while performing an additional cognitive task and an endurance test. All measures were obtained preoperatively and 6 weeks and 6 months postoperatively.

Results: Patients improved significantly over time; however, extent and speed of recovery of gait parameters differed for each test part. The relation between walking speed and step length showed systematic improvement when analyzed over a range of speeds. At 6 months, the variability coefficient of the additional task test part was comparable with the preferred walking variability coefficient. The endurance test results could be predicted from the results of preferred walking.

Conclusions: Assessment of recovery of gait function requires more than only assessment of “normal” walking. Particularly, an analysis of walking at different speeds and walking while performing an additional cognitive task demonstrate different aspects of gait recovery after THA.

Key Words: Arthroplasty, replacement, hip; Gait; Rehabilitation.

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Besides several widely used self-report questionnaires to describe recovery after total hip arthroplasty (THA), objective measures can be obtained and are considered complementary. In particular, measures of gait function are relevant to assess outcome. Because gait is highly important in everyday life, gait function is closely linked to overall functioning. For example, walking speed has been related to independent living and the ability to perform various activities of daily living, like safely crossing a traffic intersection and risk of falling. Hence, gait function is an important indicator of functional recovery. Gait function depends on the ability to maintain safe gait while navigating in a complex and changing environment, whereby gait has to be adjusted to different task demands. Thus, from a behavioral approach, important elements of gait function are the ability to walk at different speeds, combine gait with attention-demanding tasks, and walk longer distances. These aspects should be incorporated into a test battery assessing THA patients. Next to questionnaire research, predominantly limited gait analyses are performed (ie, only “normal” walking) on THA patients. With the development of ambulatory measuring devices that use body-fixed sensors, gait analysis is less time-consuming compared with the methods applied in laboratories by using camera systems, forceplates, treadmills, and electromyography. It is therefore possible to measure different aspects of gait function within an acceptable amount of time and burden. Additionally, gait analysis can be performed outside a laboratory setting, which is a more representative environment of the patients’ everyday life.

The purpose of this study is to describe the spatiotemporal measures of gait recovery after THA, whereby the different aspects of gait function are measured with an ambulatory measuring device in an extensive test protocol, including walking at 3 speeds, walking with an additional cognitive task, and a walking endurance test. The hypothesis is that this test protocol will provide measures of gait recovery that cannot be detected when only preferred walking speed is assessed.

METHODS

Participants

From September 2002 to August 2004, patients were included in the study on admission to the Orthopedic Department of the University Medical Center Groningen for a unilateral primary THA while participating in the short-stay program. Because not all patients are capable of following a short-stay program, selection was done by using the following criteria: estimated surgery time less than 120 minutes, body mass lower than 110 kg, expected hospital stay less than 6 days, absence of relevant cardiovascular comorbidity, no severe mobility disability, no psychologic dysfunction, and no severe deformity of the spine. All patients were allowed to start walking with aids on the first postoperative day and were discharged on the fifth postoperative day, unless there were complications. No physical therapy was prescribed.

Within the short-stay program, 2 groups could be distinguished. One group received usual short-stay care, another received an additional support program called the Groningen Orthopedic Exit Strategy (GOES). The GOES was developed to respond to the insecurity and inactivity many patients show during the rehabilitation period, which as a consequence of the short-stay program is moved from the hospital setting to the...
home situation and aims to provide patients with extra support. The GOES treatment consists of showing patients a video with role models, providing extra information through newsletters and telephone consultation hours, and emphasizing partner participation. The hypothesis that this treatment would lead to more self-efficacy and social support and better pain coping, and eventually result in a better and quicker rehabilitation, was not supported, as measured by questionnaires.19 Because no effect on the psychosocial variables was found, it is assumed that no differences in gait recovery between these 2 patient groups will be present and the 2 groups can be evaluated as a whole.

Design and Data Collection
All patients included in the study performed the gait analysis on admission to the hospital preoperatively and 6 weeks and 6 months postoperatively when visiting the outpatient clinic. The greatest incremental improvements in gait parameters have been shown to occur in the first 6 months after surgery.12,13,20 Additionally, a reference population consisting of relatives of the THA patients performed the gait analysis in the same way the patients did. The study was conducted in accordance with the guidelines stated in the Declaration of Helsinki and the regulations of the Medical Ethical Committee of the University Medical Center Groningen.

Measurements
For gait analysis, we used the DynaPort system, a which consists of a data recorder (dimensions, 125×95×34mm; weight, 295g) that is attached to the lower back of the patient with a neoprene belt around the waist. The data recorder contains 3 uniaxial, piezoresistive accelerometers that measure acceleration in the frontal, sagittal, and transverse planes and a memory card on which data are stored. Three penlight batteries are attached to the belt. The position of the data recorder is adjustable so that the sensors can be positioned vertically.

Measurements were performed in a normal hospital corridor under supervision of the first author. Two cones were positioned 20m apart. Patients were instructed to walk 20m at their preferred speed, to walk as fast as possible (not running), and to walk at a slow speed. Additionally, patients were instructed to walk at their preferred speed while counting backward out loud from 50, each time subtracting 3 (dual task). Finally, patients were instructed to walk at their preferred speed for 6 minutes (walking endurance test). Because we wanted a test that is representative of an everyday life situation, we chose to instruct patients to walk at their preferred speed for 6 minutes rather than instruct them to cover as much ground as possible within 6 minutes, which is the instruction in the often-used 6-minute walk test (6MWT). Patients were allowed to quit if they experienced too much pain or became too fatigued. The amount of time patients could walk and the distance they covered were measured. During all test parts, patients were allowed to use crutches if they were used to walking with them. The total test duration was about 20 minutes.

After each measurement, the data were transferred from the memory card to a personal computer by using DynaScope software and displayed graphically. The beginning and end of each test part was selected and marked by hand. Analysis of accelerometer signals and extraction of gait parameters was performed by McRoberts BV. Several movement features were obtained from the accelerometer signals. Of these features, walking speed, step length, step duration, and the standard deviation (SD) of the step durations were used in this study. The variability coefficient (variability coefficient = SD of step duration/mean step duration × 100%) was calculated to indicate individual variability in step duration.

The ambulatory method is used to determine spatiotemporal gait parameters by using lower-trunk accelerations. In previous studies, this method has been proven a valid means to determine gait parameters.17,21,22

Statistical Analysis
Descriptive statistics (mean, SD) were used to describe the total study population and the results of the gait analysis. We examined walking speed, step length, step duration, and variability coefficient in an analysis of variance with time of measurement (pretest vs 6-wk follow-up vs 6-mo follow-up) as a within-subjects factor. If the sphericity assumption was not met, we applied the Huynh-Feldt correction. A significant main effect for measurement time was analyzed by single degree of freedom, repeated contrasts. Effect sizes were computed as partial η² values.

The distance patients could walk at a preferred speed within 6 minutes was described and analyzed in a random coefficient analysis to determine if a significant improvement over time was seen. Again, the interaction term group by time was included as the covariate to test our assumption that the gait parameters of the patients of the GOES, and usual care groups were similar. Furthermore, to see whether patients showed fatigue and whether this diminishes over time, the mean values of the first and final three 20-m distances were calculated for all gait parameters at the 3 different measurement times. Consequently, patients who could not perform the walking endurance test at all or who could not walk at least six 20-m distances before quitting at 1 or more measurement times were excluded from this analysis.

We performed all statistical analyses by using the statistical package SPSS. A P value lower than .05 was considered statistically significant.

RESULTS
Demographic Characteristics
A total of 80 THA patients participated in the short-stay program during the inclusion period of the study. Ten of them could not perform the second or third measurement or both and were therefore excluded: 2 patients had severe complications and were unable to walk, 3 patients had health problems unrelated to the arthroplasty at the time of the third measurement, 2 patients did not show up at the outpatient clinic for unknown reasons, 1 patient moved out of the country, and 2 patients underwent an arthroplasty of the contralateral hip before the final measurements took place. These 10 patients had a mean age of 62.2 years, and 70% were women. Body mass index was 29.2 kg/m². Six other patients had to be excluded because of technical problems and 1 patient because of the fact that not all test parts of 1 measurement were performed. The data of 63 patients were therefore available for analysis. One person from the reference group had to be excluded because of technical problems so the data of 19 persons were used in the analysis.

Table 1 presents baseline characteristics of the patients and the reference population. The patients’ mean age was 62.0 years, and most (68.3%) patients were women. There were no significant differences between the patients and the reference group on any variable. Mean hospital length of stay (LOS) was 7.0±3.3 days. The mean LOS was raised by 1 patient with an LOS of 26 days because of an infection and prolonged wound leakage. Not including this particular patient, the mean LOS was 6.7±2.3 days.
Gait Parameters

Gait characteristics for the THA patients as well as for the reference population are displayed in table 2. All main effects for measurement time were significant with a P value lower or equal to .001, meaning that on all gait parameters and on all test parts, the patients improved significantly over time.

Between the preoperative and 6-week postoperative measurements, walking speed improved significantly only in the slow-walking and the dual-task test parts, whereas step length and the variability coefficient improved significantly in the slow-walking, preferred-walking, and dual-task test parts. Step duration did not improve significantly in any test part. Between the 6-week and 6-month postoperative measurements, significant improvement was seen in walking speed, step length, and step duration in all test parts. The variability coefficient improved significantly only in the fast walking and dual-task test parts. The relation between the parameters of step length and walking speed for the 3 measurement times is shown in figure 1.

Between the different test parts preoperatively, most variability was seen in the dual-task test part (fig 2). At 6 weeks, all variability coefficients improved, except in the fast-walking task part. Still, the variability coefficient observed in the dual-task test part was the highest. At 6 months postoperatively, most variability was seen in the slow-walking test part.

Patients improved significantly in the distance they could walk within 6 minutes \((F_{1,710} = 43.68, P < .001; \text{partial } \eta^2 = .41)\). Preoperatively, 294.0 \pm 103.8 m were covered on average, 315.9 \pm 75.3 m at 6 weeks, and 387.4 \pm 79.5 m after 6 months. On average, the reference group walked 475.6 \pm 49.2 m. Preoperatively as well as postoperatively, most patients were able to walk for 6 minutes. The mean values of the first and final three 20-m distances were calculated for all gait parameters at the 3 different measurement times (table 3). Six patients who could not walk at least six 20-m distances were excluded from this analysis. Patients improved significantly over time on the difference between the first and final mean values of the parameters walking speed, step length, and step duration \((P < .05)\); at 6 months, the mean walking speed of the final three 20-m distances was even higher than the mean walking speed of the first 3. Differences between measurement times were very small though; this was expressed in low partial \(\eta^2\) values (.11, .06, .11, respectively). No significant improvement was seen on the difference between the mean first and final three 20-m distances of the variability coefficient.

Of the 63 included patients, 35 received the GOES treatment. The GOES patients were comparable on all patient characteristics measured at baseline to the group of patients receiving usual short-stay care. No significant group by time effect was found on any of the gait parameters of the slow-, preferred-, and fast-walking or dual-task test parts; the patients of the GOES group did not improve significantly over time any differently than those of the usual short-stay group. The walking endurance test showed no difference between the 2 groups either. The 2 groups differed in the use of aids during walking at 6 weeks, but this did not result in a difference between groups on the gait parameters. It was therefore justified to perform the analyses with the overall group.

DISCUSSION

The purpose of this study was to describe gait recovery after THA based on spatiotemporal gait parameters measured by an ambulatory measuring device while using a test protocol that includes walking at 3 speeds, walking with an additional cognitive task, and a walking endurance test. Our hypothesis was that this test protocol provides measures of gait recovery that cannot be detected when only walking at a preferred speed is assessed.

The results of the study showed that the test protocol provided added value over measurement of only preferred speed. Six weeks after surgery, the results of walking at a preferred speed indicate a very small increase in walking speed and step length and a small decrease in gait variability (variability coefficient). A larger increase in speed and step length is first seen after 6 months. In contrast, already after 6 weeks, the speed–step length relationship during walking at different speeds shows a small but consistent increase in speed and step length (see fig 1). In addition, the assessments of walking at a fast speed show a large speed and step length increase between 6 weeks and 6 months after surgery. In accordance with findings of others,25 our data of walking at different speeds show that gait variability is speed dependent before surgery (see fig 2).

Six weeks after surgery, no decrease of gait variability with speed is seen; instead, gait variability increases slightly. However, after 6 months, an overall decrease of gait variability can be seen and again gait variability decreases with increasing speed. Some caution is needed when interpreting these data because most patients used walking aids 6 weeks after surgery, which might have influenced gait variables.24 All of these findings would not have been obtained if only gait at 1 speed had been analyzed, as is done in most of the previous research.1,10,12-14,25-27 Kyriazis and Rigas28 did analyze gait parameters at 2 speeds; they compared preferred and fast speed of 25 patients preoperatively and 1 and 8 to 10 years after the THA with a conductive walkway system by using telemetry. They concluded that fast walking did not provide information that was not already shown in preferred gait. However, our results show that analyzing gait by assessing walking at 3 different speeds offers more insight in recovery of gait function after THA than assessments of preferred walking alone. As is also shown by our results on gait variability, an additional advantage of assessing gait at different speeds is that when other aspects of gait are studied (eg, muscle activities, angular displacements, trunk accelerations), the test protocol can take into account the speed dependency of these aspects.10,29

Walking while performing an additional attention-demanding cognitive task is a means to measure whether patients are able to walk automatically.4 To our knowledge, this is the first study that uses this measure in THA patients. Analysis is based on the principle of dual-task interference, which is the worsening of performance of the main task (eg, walking) as a result of simultaneously performing an attention-demanding cognitive task (eg, counting backward). Automaticity of the main task is reflected by a low or absent dual-task interference effect. Measuring the interference effect over time gives an indication of the level of returning automaticity.6 The dual-task principle has been used in other orthopedic patient populations (eg, after limb-saving surgery of the lower limb).30 Nonautomaticity can
Table 2: Gait Parameters and Results of the General Linear Model Analysis

<table>
<thead>
<tr>
<th>Patient Group (N=63)</th>
<th>Preoperatively</th>
<th>6 Weeks</th>
<th>6 Months</th>
<th>GLM RM (main time effect)</th>
<th>GLM RC (preop to 6wk)</th>
<th>GLM RC (6wk to 6mo)</th>
<th>Reference Group (n=19)</th>
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Walking at slow speed

<table>
<thead>
<tr>
<th>Speed (m/s)</th>
<th>0.74±0.16</th>
<th>0.80±0.17</th>
<th>0.89±0.16</th>
<th>F_{1,124}=37.12</th>
<th>F_{1,62}=8.41</th>
<th>F_{1,62}=36.96</th>
<th>0.92±0.13</th>
</tr>
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Walking at fast speed

<table>
<thead>
<tr>
<th>Speed (m/s)</th>
<th>1.14±0.26</th>
<th>1.13±0.21</th>
<th>1.37±0.25</th>
<th>F_{1,124}=57.11</th>
<th>F_{1,62}=0.01</th>
<th>F_{1,62}=141.43</th>
<th>1.73±0.17</th>
</tr>
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Walking with additional task

<table>
<thead>
<tr>
<th>Speed (m/s)</th>
<th>0.79±0.21</th>
<th>0.85±0.21</th>
<th>0.99±0.21</th>
<th>F_{1,62}=6.65</th>
<th>F_{1,62}=6.65</th>
<th>F_{1,62}=52.37</th>
<th>1.09±0.16</th>
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</thead>
</table>

<table>
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<tr>
<th>Step length (m)</th>
<th>0.51±0.08</th>
<th>0.55±0.08</th>
<th>0.58±0.09</th>
<th>F_{1,62}=4.20</th>
<th>F_{1,62}=8.20</th>
<th>F_{1,62}=20.51</th>
<th>0.67±0.07</th>
</tr>
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</table>

<table>
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<tr>
<th>Step duration (s)</th>
<th>0.71±0.10</th>
<th>0.71±0.09</th>
<th>0.65±0.07</th>
<th>F_{1,62}=0.11</th>
<th>F_{1,62}=0.11</th>
<th>F_{1,62}=4.93</th>
<th>0.63±0.10</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Variability coefficient (%)</th>
<th>13.1±5.8</th>
<th>10.4±4.6</th>
<th>10.5±4.0</th>
<th>F_{1,62}=7.43</th>
<th>F_{1,62}=10.35</th>
<th>F_{1,62}=0.02</th>
<th>8.2±2.7</th>
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Walking at preferred speed

<table>
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<tr>
<th>Speed (m/s)</th>
<th>0.93±0.19</th>
<th>0.95±0.17</th>
<th>1.14±0.18</th>
<th>F_{1,62}=56.16</th>
<th>F_{1,62}=0.99</th>
<th>F_{1,62}=105.74</th>
<th>1.32±0.15</th>
</tr>
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<table>
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<tr>
<th>Step length (m)</th>
<th>0.56±0.09</th>
<th>0.58±0.08</th>
<th>0.63±0.10</th>
<th>F_{1,62}=16.17</th>
<th>F_{1,62}=7.86</th>
<th>F_{1,62}=8.20</th>
<th>0.71±0.07</th>
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<tr>
<th>Step duration (s)</th>
<th>0.61±0.07</th>
<th>0.62±0.07</th>
<th>0.55±0.04</th>
<th>F_{1,62}=30.08</th>
<th>F_{1,62}=0.38</th>
<th>F_{1,62}=6.29</th>
<th>0.54±0.03</th>
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<tr>
<th>Variability coefficient (%)</th>
<th>12.0±5.6</th>
<th>10.5±3.6</th>
<th>9.6±3.1</th>
<th>F_{1,62}=7.55</th>
<th>F_{1,62}=6.27</th>
<th>F_{1,62}=2.69</th>
<th>8.1±3.2</th>
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</table>

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<tr>
<th>Step length (m)</th>
<th>0.56±0.09</th>
<th>0.58±0.08</th>
<th>0.62±0.10</th>
<th>F_{1,62}=21.3</th>
<th>F_{1,62}=1.42</th>
<th>F_{1,62}=14.89</th>
<th>11.0±5.9</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Step duration (s)</th>
<th>0.73±0.14</th>
<th>0.71±0.11</th>
<th>0.63±0.07</th>
<th>F_{1,62}=8.20</th>
<th>F_{1,62}=1.42</th>
<th>F_{1,62}=4.93</th>
<th>14.0±3.8</th>
</tr>
</thead>
</table>

| Variability coefficient (%) | 14.0±8.7 | 11.7±5.9 | 10.0±4.0 | F_{1,62}=7.85 | F_{1,62}=4.40 | F_{1,62}=0.02 | 7.4±3.8 |

NOTE: Values are mean ± SD.
Abbreviations: GLM RC, general linear model repeated contrasts; GLM RM, general linear model repeated measures.
have an impact on daily living; gait changes caused by performing an additional cognitive task while walking are associated with increased risk of falling among older adults.\textsuperscript{31}

Our results indicate that the inclusion of a dual task is valuable as a means to determine (recovery of) gait automaticity. Particularly the variability coefficients showed improved gait during dual-task performance. Already after 6 weeks, gait variability is reduced. After 6 months, gait variability has further reduced and does no longer differ from the variability that can be expected based on the chosen gait speed (see fig 2). During dual-task conditions, gait speed, but not step length, is reduced in comparison to preferred walking. However, this reduction in gait speed is smaller after 6 months than preoperatively or after 6 weeks. Thus, all our results indicate a return of gait automaticity.

The results of the walking endurance test did not show the expected decrease in speed and step length and increase in gait variability when the first and final 20-m distances were compared. The results also did not show the expected improvement after surgery. Existing differences, although statistically significant, were very small and cannot be considered as clinically relevant. Whether or not a patient completed this test part, the results from the longer walking distance could already be predicted from the results of walking at preferred speed.

Results of the dual-task test part presented an unexpected interference that has not been reported in other similar studies: the association between walking speed and step length deviates from the association seen in the other test parts. The tendency to enunciate a number at each step resulted in a slow gait with relatively large step lengths, which can be because of the rhythmic character of additional task interfering with the walking rhythm.\textsuperscript{32} In gait research, there are different attention-demanding tasks that vary in complexity and suitability for different populations and age groups. Gait research on patients recovering from limb-saving surgery of the lower limb has used the auditory Stroop test.\textsuperscript{30} Further research is necessary to determine the applicability of this test in THA patients; some consider this task less appropriate for older adults who often have difficulties hearing.\textsuperscript{32} Moreover, it is advised that patients also perform the cognitive task as a single task (eg, while sitting down) so that performance on the task with and without walking can be compared too.\textsuperscript{31} In our study, we found that performing an additional cognitive task affects gait parameters. In theory, patients can also perform worse on the additional task and not on walking, despite the instructions to direct attention to the counting task while walking. This might be a sound “safety-first” strategy, but with this strategy changes in performance of the cognitive task remain unrecognized.

The walking endurance test appeared not to be a measure of endurance. Either the test has to be prolonged, which makes it difficult to incorporate into daily clinical practice, or the instruction should be given to walk as fast as possible, which is done in the protocol of the 6MWT. We considered this as not representative of independent functioning in daily life. However, comparison with previous studies performed by using the 6MWT is therefore impossible. We do have to keep in mind that the measurements were assessed in relatively healthy patients because only patients without other health problems could participate in the short-stay program. Additionally, 6 patients could not perform the test. These patients did complete the slow-, preferred-, and fast-walking test parts and performed worse on all parameters at all 3 measurement times than the included patients. A remarkable observation during the endurance test was that patients walked faster than during the walking at preferred-speed test part. This occurred despite the fact that participants were instructed to walk at their preferred speed in both test parts. The walking endurance test might be experienced as a competition. Thus, despite instructions, some
participants may want to cover as many meters within the 6 minutes as possible. Another explanation is that walking the 20-m walkway several times back and forth is experienced differently than walking it once. It has been observed that gait speed on a long walkway (eg, 60m) is higher compared with short walkways.33

The administration of the measurements was easy and well accepted by all patients. None reported any discomfort caused by the portable measuring device so any possible influence thereof on gait can be neglected. The total duration of a measurement was approximately 20 minutes and can therefore be integrated into routine clinical practice.

Replacing the walking endurance test with a “walking on different ground surfaces” test part seems relevant and can be the object of future research.7,16 Patients often complain about problems when walking on uneven pathways, especially after surgery. This can be the result of balance problems because it is known that balance during gait is altered by severe osteoarthritis, and some of these balance problems seem to remain after THA.34 Stability during walking should therefore be assessed while walking under circumstances that challenge the postural control system to obtain an indication of patients’ ability to respond to multiple, irregular perturbations.35 With the ambulant measuring device, tests can be performed outside the laboratory. Hence, gait can be studied under more complex, unpredictable, and real-life circumstances, and this may reveal essential information, as is also indicated by the results of our dual-task test part.

CONCLUSIONS

In this study, a test protocol consisting of walking at 3 different speeds while performing an additional cognitive task and an endurance test was used to obtain insight into recovery of gait function after total hip replacement. The hypothesis that the test protocol would provide measures of gait recovery that cannot be detected when only preferred walking speed is assessed was confirmed by a part of our results. First, the use of different speed instructions made it possible to analyze gait parameters and an endurance test was used to obtain insight into recovery of gait function after total hip replacement. The hypothesis that replacement of the walking endurance test with a “walking on different ground surfaces” test part seems relevant and can be integrated into routine clinical practice.

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Acknowledgments: We thank Sander Heikens and Rienk van der Slikke, from McRoberts BV, for their technical assistance.


36. Kayara A, van den Akker-Scheek. Suppliers

b. Version 12.0.1; SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.