METHODS

Subjects

In study 1 and 2, respectively, 20 older adults (10 males, 10 females; mean age = 68.5 years, SD = 7.4) and 5 older adults (1 male, 4 females; mean age = 73.0 years, SD = 6.2) were included. Exclusion criteria were: impairments or diseases (e.g. orthopedic, neurological) that could affect the performance of daily activities such as walking, getting in and out of a chair or bed. The subjects lived independently in the community. All participants gave informed consent prior to the study. The studies’ procedures were approved by the Medical Ethical committee of the University Medical Center Groningen.

Materials

The DynaPort MiniMod (McRoberts BV, The Hague, The Netherlands) contains three orthogonal orientated piezo-capacitive acceleration sensors, each measuring at a sample rate of 100 Hz. Data is stored on an SD card. The device (size 84 x 50 x 8 mm; weight 44.5 g) is placed in a neoprene belt which is strapped around the waist. It is positioned at the lower back, between and above the posterior superior iliac spines. The MiniMod was placed and ready for measurement in about one minute.

Procedure
Subjects answered a questionnaire concerning questions about their health status and medical history. In study 1, a chair, a three-step stair, a bed and a table had been arranged in a movement laboratory (figure 1).

Figure 1 Set-up in the movement laboratory

First, several mobility-related activities were performed in a fixed order: walking 4.5 m, sitting in the chair, walking 2.3 m, stair walking, walking 1.4 m, lying supine and side-lying (right/left) in the bed,
walking 1.4 m, stair walking, walking 2.3 m, picking up a tray with two cups from a table and walking 4.5 m. The subjects had to stand still for approximately 3 seconds after each activity at lines marked on the floor. A test instructor walked alongside the subject and indicated when to start the next activity. This fixed sequence was performed five times consecutively. If necessary, the subjects could take a break.

Thereafter, the subjects were allowed to move freely for 3 minutes with the only instruction that taking the stairs, sitting in the chair and lying in the bed had to be completed at least once. All measurements were recorded on video. The video camera was positioned perpendicular to the set-up, so the activities were mainly assessed from a side view.

For study 2, subjects were monitored about 30 minutes in their home environment while performing similar activity sequences as in study 1: sitting in a chair, lying in the bed, walking 15 m outside, stair walking (if present), taking a tray from one table to another table and several walking periods in between. Also, the subjects were asked to carry out common tasks in and around the house such as doing the dishes, watering plants, hanging up laundry or mowing the lawn. A test instructor gave directions to the subjects and recorded the subjects’ movements with a handheld video camera.

Data-analysis

The video-recordings were digitized and scored in a video analysis program designed in MATLAB®. A research assistant and a human movement sciences student independently observed 10 subjects to determine the inter-rater reliability of activity durations based on observations of the start and end of walking (including stair walking), sitting, standing and lying. Intraclass correlation coefficients (two-way random, absolute agreement) values were respectively 0.95, 0.78, 0.99 and 0.98. The remaining videos were scored by a single observer whose ratings were used for evaluation.
Walking was determined when the heel of the foot for the initial step cleared the ground until the foot of the closing step made complete contact with the floor and the number of steps taken being 2 or more. A step was defined as a forward displacement of the foot together with a forward displacement of the trunk. Persons were considered to be sitting when they were in a seated position, that is the upper body upright and at a 90 degree angle to the legs. Standing was determined when the subject was in an upright position with no or a small displacement, but not distinctive steps, of the feet. Lying was defined as the person being in a horizontal position and either the side or the back of the body contacted the bed completely.

All activities were coded by a number representing one of the activity categories. Postural transitions (standing to sitting or lying and vice versa) were not scored, but left open as blank time periods. The video-recordings in the home environment were observed by a human movement sciences student. Because more situations were expected where subjects would not walk, but also would not completely stand still, e.g. when working in the kitchen, the category shuffling was included and defined as locomotion by means of one step or multiple incomplete steps.

The acceleration data was uploaded on an internet site (www.gaitweb.nl) of the supplier for blinded analysis. The MoveMonitor gait and posture detection algorithm consists of five major parts. The first step is gait period detection, based on an intensity threshold. These potential gait periods are scanned using frequency analysis and a validated step detection method [1 – 3], resulting in three categories: walking, active (not walking) and static periods. Secondly, transition detection is performed to identify upward or downward transitions. The result is a Boolean vector identifying two classes: “up” (standing) and “down” (lying or sitting). Subsequently, angle calculation based on sensor tilt is used to determine if the “down” part of this vector can be identified as lying (< 30 degrees) or sitting. Next, shuffling separation divides the active (not walking) parts into two categories: shuffling and transitions.
Shuffling is defined as all movement from A to B that is not walking. If the number of steps is less than 3 or the intensity and direction of the motion do not comply with the characteristics of walking, the movements are classified as shuffling. Finally, larger transitions (e.g. standing to lying) are split in two and merged with the activity before and after the transition. Figure 2 illustrates the different stages of the MoveMonitor algorithm.
The results of the software analysis were returned by e-mail in excel-files. The reports listed the start and end times of each activity together with the associated classification category.
The performance of the activities as observed on video was taken as ‘the gold standard’. The video scores and the results of the MoveMonitor were compared in a program also designed in MATLAB. After synchronization of the video and the MoveMonitor data, the correspondence between the activity codes was determined with a time resolution of 0.1 s. The percentage correspondence and non-correspondence between the 2 methods have been calculated for all activity data (i.e. over all subjects).

Subsequently, sensitivity, specificity and predictive values were calculated per subject for each activity category, for example, ‘sitting’, as:

1. Sensitivity = (total duration that the video observation and the MoveMonitor corresponded at the same moment for ‘sitting’ / total duration that ‘sitting’ was observed on video) • 100%
2. Specificity = (total duration that the video observation and the MoveMonitor corresponded at the same moment for ‘not sitting’ / total duration that ‘not sitting’ was observed on video) • 100%
3. Positive predictive value = (total duration that the video observation and the MoveMonitor corresponded at the same moment for ‘sitting’ / total duration that ‘sitting’ was reported by the DynaPort analysis) • 100%.

Agreement scores were also calculated per subject, taking all activity categories together as:

4. Agreement = (total duration that the video observation and the MoveMonitor corresponded at the same moment for all categories / total duration that the activities were observed on video) • 100%.

Descriptive statistics and calculations were performed in SPSS 15.0 and Microsoft Office Excel 2007.

REFERENCES


### RESULTS

Activity characteristics based on the video analysis

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
<th>Mean duration ± SD</th>
<th>Total duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Laboratory</td>
<td>Home</td>
<td>Laboratory</td>
</tr>
<tr>
<td>Lying</td>
<td>Fixed</td>
<td>Free</td>
<td>Fixed</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>36</td>
<td>17</td>
</tr>
<tr>
<td>Sitting</td>
<td>166</td>
<td>75</td>
<td>40</td>
</tr>
<tr>
<td>Standing</td>
<td>896</td>
<td>78</td>
<td>308</td>
</tr>
<tr>
<td>Walking</td>
<td>800</td>
<td>339</td>
<td>332</td>
</tr>
<tr>
<td>Shuffling</td>
<td>-</td>
<td>-</td>
<td>181</td>
</tr>
<tr>
<td>All</td>
<td>1962</td>
<td>528</td>
<td>878</td>
</tr>
</tbody>
</table>

Mean duration is expressed in seconds and total duration in minutes. The number of sitting periods also comprises sitting on the edge of the bed before standing up.

In study 1, approximately 40% of sitting was classified as lying or standing in the fixed sequence. For this task, 15 of 100 sitting periods in a chair and 44 of 66 sitting periods on the edge of the bed remained undetected. In the free sequence, sitting was classified incorrectly particularly as standing. For this task, 18 of 53 sitting periods in a chair and 9 of 21 sitting periods on the edge of the bed were not detected.
The overall correspondence for standing was lower in the free sequence compared to the fixed sequence, due to a higher percentage of classifications as locomotion. Respectively, 4 and 13 standing periods were missed in the fixed and free sequence. Walking classified as shuffling in the fixed sequence included 89 times the 1.4 meter trajectory and 20 times taking the stairs.

In study 2, approximately 80% of sitting and standing was detected correctly. Six sitting periods (2 in a chair, 4 on the edge of the bed) were missed, but also 6 sitting periods that had been detected were misclassified as standing.