Technology supported geriatric assessment

Sandra Hellmers, Clemens Büse, Lena Dasenbrock, Andrea Heinks, Jürgen M. Bauer, Andreas Hein, Sebastian Fudickar

Abstract Healthy aging is a core societal aim especially regarding the demographic change. But with aging functional decline can occur and this is one of the major challenges for health care systems. For the evaluation of health of elderly and identification of early changes associated with functional and cognitive decline, clinical geriatric assessments are a well-established approach. Ideally, the assessments should take place at home of the elderly or even in their daily life.
Therefore, we introduce a technology supported geriatric assessment as an intermediate step to a home-assessment or in future to sensor-based-assessments in daily life. Beside various ambient sensors, a sensor belt is used during the assessments and for one week in the participants daily life. We discuss the suitability of our measuring devices for an ambient home-assessment and evaluate the sensors in comparison to valid measurements. Light barrier measurements show a high sensitivity and a good correlation to valid measurements.

1 Introduction

Facing the challenge of demographic change, healthy aging is a core societal aim in our societies. With aging functional decline can occur and the elderly loose physical and mental abilities. A geriatric assessment is a well-established instrument to identify early changes associated with functional and cognitive decline, like they can occur in frailty or sarcopenia, which are common geriatric syndromes. Functional ability, physical health, cognition and mental health, and socioenvironmental

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circumstances of the elderly [1, 2] are evaluated in such an assessment.
It is important to recognize early changes, because complex interventions can improve or maintain physical function, reduce the rate of falls and help the seniors to maintain their independence [3]. But it's not an easy task to identify older adults at risk of functional decline at an early stage and to initiate preventive measures, where they are needed most. Due to the high effort and costs of a manual functional assessment, technology support can enable more extensive and frequent or even long-term measurements. Consequently this allows a more detailed and current perspective of the health of patients and interventions can be initiated earlier.
Most geriatric assessments take place in hospital or medical offices. But optimally, the assessments should take place at home of the elderly or even in their daily life. This could possibly be realized by new technologies. One major question is: Can specific sensors deliver similar results as a functional assessment and reduce efforts and costs?

To make an intermediate step to a home-assessment or in future to sensor-based-assessment in daily life the assessments are supported by technology. In addition to ambient sensors such as light barriers, a portable force plate and the aTUG (ambient Timed Up & Go) system, a wearable sensor belt is used. Each assessment item shall be mapped with the sensor data of the wearable device and analyzed afterwards. After this assessment the participants are asked to wear the sensor belt for one week. This allows rather continuous measurement of participants' behavior and items of activities of daily living and is possibly the next step to a daily life assessment.

Thus, within our project for primary prevention for healthy aging, a clinical screening study is carried out to identify possible indicators for a functional decline. The study aims at the development of delta measures (difference between the results of two measures with more than 6 months between them) to predict the need for long term care based on low cost consumer sensors.

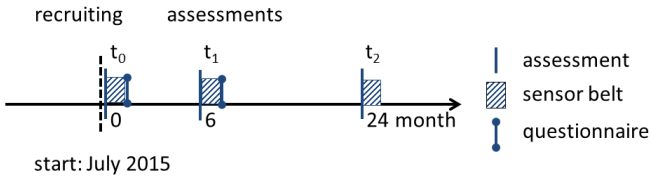


Fig. 1 Timeline of the clinical study. Participants pass the functional assessment 3 times within 2 years. After the assessment the participants wear a sensor belt for one week and record their activities in a diary. In addition a questionnaire will be completed by the elderly. At the measuring time t_0 the questionnaire contains questions about the socioenvironmental circumstances.

The functional assessments are perfoprmed on about approximately 260 participants aged 70 and above at baseline (t_0), after 6 months (t_1) and 24 months (t_2) (see Fig.

1). We aimed to obtain a representative sample in this age group in terms of sex and socioeconomic status. At this time already 170 older healthy adults participated in our study. The mean age is 75.8 years, in a range from 70 to 87 years. 105 participants are female (61.8%) and 65 participants are male (38.2%).

Some important assessment items entailed in our study are not directly applicable in home-assessments. But the developed predictors for functional decline on the basis of technology measurements and the evaluation of ambient devices for integration into home environment, provide a foundation for next steps.

2 Technology supported assessment

In order to analyze the suitability of ambient technology for home assessment of functional status of elderly, we use various ambient devices in our study, which are described in the following. The combined assessment items of multiple common clinical assessments and the employed measurement devices for each item are described in this section.

Table 1 Employed measurement devices within the assessment items.

category	measurement device	measured value	assessment item
ambient	light barrier	walking speed, leg strength, endurance	6MWT, SPPB, frailty index, SCPT
ambient	aTUG system	mobility, strength	TUG, SPPB
ambient	force plate	balance, jump power/leg strength, mobility	CMJ, DEMMI, SPPB
special devices	hand grip dynamometer	Grip strength	frailty index
special devices	bio-impedance measuring device	body composition, muscle mass	BIA
special devices	stadiometer	height, weight, BMI	BMI
body area	sensor belt	Walking speed, balance, mobility, leg strength, jump power, mobility	6MWT, SPPB, frailty index, SCPT, TUG, DEMMI, CMJ

Table 1 lists the used measurement devices, the measuring values and the performed assessment items. Due to the high relevance of mobility, balance and strength for healthy aging these assessment items are supported by ambient technology. Light barriers are measuring the walking speed, leg strength and endurance during the short physical performance battery (SPPB), frailty index, stair climb power test (SCPT) and 6 minute walk test (6MWT). Mobility and strength are measured by the ambient Timed Up & Go (aTUG) system during the timed up & go (TUG)

and the chair-rising-test, which is an item of SPPB. The force plate measures the balance and strength during the SPPB, the balance tests of the de Morton Mobility Index (DEMMI) and the counter movement jump (CMJ). Special devices such as bio-impedance measuring device, stadiometer and handgrip dynamometer are used for bio-impedance analysis (BIA), measurements of the body mass index (BMI) and for evaluating grip strength, which also provide important criteria for health. The wearable sensor belt records each assessment item. The data shall be analyzed and mapped to each assessment item.

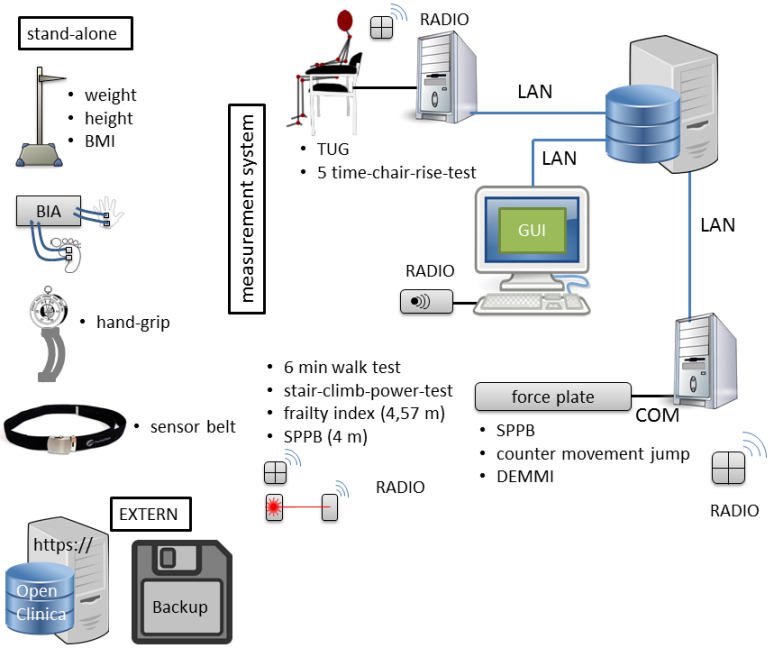


Fig. 2 Measurement system of the technologically supported functional assessment with its single components and the corresponding assessment items, data storage and documentation.

The resulting complete measurement system with its specific components is shown in Figure 2. Beside stand-alone devices like stadiometer, sensor belt, bio-impedance measuring device and hand-grip dynamometer the other devices are connected with a measuring computer. The measuring computer receives the data recorded by the aTUG system and the force plate via LAN and the radio signals of the light barriers via radio receiver.The distances for the walk tests in the measuring room are marked by tape on the floor. Various remote controls transmit start and stop signals for the different assessment items. The measurement program assembles the data, calculates the walk test duration on basis of the remote controls triggers and stores the data afterwards. The documentation of the assessments is conducted using Open

Clinica.
The ambient and wearable devices provide objective data and are independent of subjective influences like potential different reaction times of the experimenter. For a good reliability it is necessary to verify the correct functionality and to ensure a high sensitivity. As a result, the early recognition of measurement errors is essential. A redundant system prevents the loss of data in such a case.
The measuring devices and the performed assessment items, listed in Table 1, are described in the following.

2.1 Ambient sensors

Light barriers
Light barriers are applied to measure walking time and walking speed for various distances at the specific assessment items. A walking test with a distance of $4\,m$ is performed in the Short Physical Performance Battery (SPPB) [9], $4.57\,m$ in the frailty index [14]. These tests are performed in the measuring room and are used to evaluate the walking speed.
The endurance is tested by the $6\,min$ walk test (6MWT). During 6 minutes the participants are walking along the corridor over a distance of $20\,m$ and return. One benefit of light barriers within the $6\,min$ walk test is the fact, that the time of the turn at the end of the walking route and the associated deceleration can be excluded from the calculation of the walking speed.
The stair climb or leg power can be determined by the stair climb power test (SCPT) [7]. The stair climb power (SCP) can be calculated by following equation:

$$SCP = m \cdot g \cdot h \cdot t^{-1}, \tag{1}$$

where m is participants mass in kg, g is gravity acceleration ($9.81\,ms^{-2}$), and h is the height of the staircase in m [8].

aTUG system
The ambient Timed Up & Go device (aTUG) [10, 11] includes light barriers, force sensors and a laser rangefinder. Thereby, it is able to detect the sit to stand cycle and to make detailed gait analyzes. Figure 3 shows the aTUG system. The aTUG has been validated to measure reliably and precisely the total duration of TUG and durations of the single components of this sequence with mean error of only 0.05 seconds and mean standard deviation of 0.59 seconds using especially its force and range measurements [11]. The aTUG system supports the Timed up & Go test [4] and the 5 time chair rise test within the Short Physical Performance Battery (SPPB) [9].

Force plate & hand grip dynamometer
To evaluate the balance, the mobility and the strength of the lower extremity the

Fig. 3 The ambient Timed Up & Go (aTUG) device includes light barriers, force sensors and a laser range scanner. The device is able to detect the sit to stand cycle and to make detailed gait analyzes.

Short Physical Performance Battery (SPPB) [9] and the de Morton Mobility Index (DEMMI) [12] are performed by the participants on a portable force plate. The force plate is also used the counter movement jump.
The AMTI accupower force plate is specified for jumping and power analyzes. Beside forces, power and velocity measurements the plate is also able to measure the center of pressure or mass and is suitable for balance analyzes. The AccuPower sensitivity is based on a $8900N$ full scale F_z capacity and a 12 bit internal AD ($\pm 2048\,bit$) or about 4.3 N/bit.
The measurement of grip strength [13] with a hand grip dynamometer is an assessment item of the frailty index [14]. The hand grip dynamometer of JAMAR has an accuracy of $\pm 5\%$of scale.

2.2 Medical-sensors

Body mass index, bio-impedance analysis
Before the technology supported assessment items start, the independent living skills of participants are collected by the Instrumental Activities of Daily Living Scale (iADL) questionnaire [5]. The Barthel index [6] is used to score the self-sufficiency and care dependency. In addition to the body mass index the body composition and muscle mass is determined by a bio-impedance analysis (BIA). The body mass index is measured by a stadiometer (seca, measuring station, seca 285) with an accuracy of $\pm 2\,mm$ in height measurements and of $\pm 50\,g$ in a weighting range between $25\,kg$ to $100\,kg$ and $\pm 75\,g$ in a weighting range between $100\,kg$ to $150\,kg$. The bio-impedance measuring device has an accuracy of $\pm 2\,\Omega$ for the resistance R_z and $\pm 1\,\Omega$ for the reactance R_x.

2.3 Body area sensors

Sensor belt
During the functional assessment items the participants wear a sensor belt by Humotion (see Figure 4). One aim of the study is to compare and to identify the single functional assessment items with the sensor data of the belt and to answer the question if the sensor belt provides equal or even more information or results as a conservatively measured geriatric assessment. Maybe wearing the sensor belt in daily life can be engaged instead of a functional assessment to get the same results in the future. The belt includes four sensor types. A triaxial accelerometer, which

Fig. 4 Sensor belt with triaxial accelerometer, gyroscope magnetometer and barometer.

measures the acceleration force in $g \approx 9.81\,ms^{-1}$ applied to the device on all three physical axes (x, y, and z), including the force of gravity. The gyroscope measures a device's rate of rotation in $deg \cdot s^{-1}$ around each of the three physical axes (x, y, and z) and the magnetometer measures the ambient geomagnetic field for all three physical axes (x, y, z) in μT. The barometer gauges the ambient air pressure in hPa. The sensors included in the belt are listed in Table 2. The belt is worn till the end of

Table 2 The specifications of the sensors included in the belt.

sensor	frequency	resolution	range
accelerometer	100 Hz	12 bit	± 16 g
gyroscope	100 Hz	14 bit	$\pm 2000\,deg \cdot sec^{-1}$
magnetometer	100 Hz	12 bit	$\pm 500\,\mu$T
barometer	100 Hz	14 bit	-

the assessment. Following the assessment, participants will be requested to wear the described sensor belt for one week as well as to keep an activity log to document activities like stair climbing or walking.
On the basis of the measured data a detailed analysis of the participants' behavior and their activities of daily living can be made. There are already existing algorithms detecting steps or activities like standing, sitting, lying or climbing stairs [17, 18].

3 Validation of the light barrier measurement system

While most sensing devices are validated, the light barriers have to be validated due to the specifics associated with the placement. The results of the ambient measured assessment items and valid measurements by study nurses and physical therapists are compared in regard to correlation and differences. In our study light barriers are tested for indoor walking speed measurements and for evaluating the stair climb or leg power.

Method of testing

The reliability and validity of the light barrier measurement system will be examined via correlations between already validated clinical tests and technology-based tests. Validity is measured by sensitivity and specificity. To determine the validity of our measuring system we compare the technology-based test results with the results of conventional geriatric assessment items.

The measured values are continuous diagnostic variables. There are specific cut-off values for each assessment item, which divide the results into categories. To validate the light barrier system we need to identify these categories to define the sensitivity and specificity for each item.

The cut-off value for the time over a distance of 4.57m (frailty index) is $7\,s$ for men with a height of $\leq 173\,cm$ and $6\,s$ for a height of $> 173\,cm$. The cut-off value for a women is $7\,s$ with a height of $\leq 159\,cm$ and $6\,s$ with a height of $>159\,cm$ [14].

The cut-off value (lower limit of normal) for the 6 min walk distance d_{6min} for healthy adults is calculated by following reference equations from Enright et al. [15]:

$$\text{Men:} \quad d_{6min} = (7.57 \cdot h) - (5.02 \cdot a) - (1.76 \cdot w) - 309 - 153 \tag{2}$$

$$\text{Women:} \quad d_{6min} = (2.11 \cdot h) - (5.78 \cdot a) - (2.29 \cdot w) + 677 - 139, \tag{3}$$

where h is the height in cm, a is the age in years, w the weight in kg.

For example the minimum distance within the 6min walk test of a 75-year old healthy men, weight $80\,kg$ and height $180\,cm$ should be $415.7\,m$ to fit within the normal range.

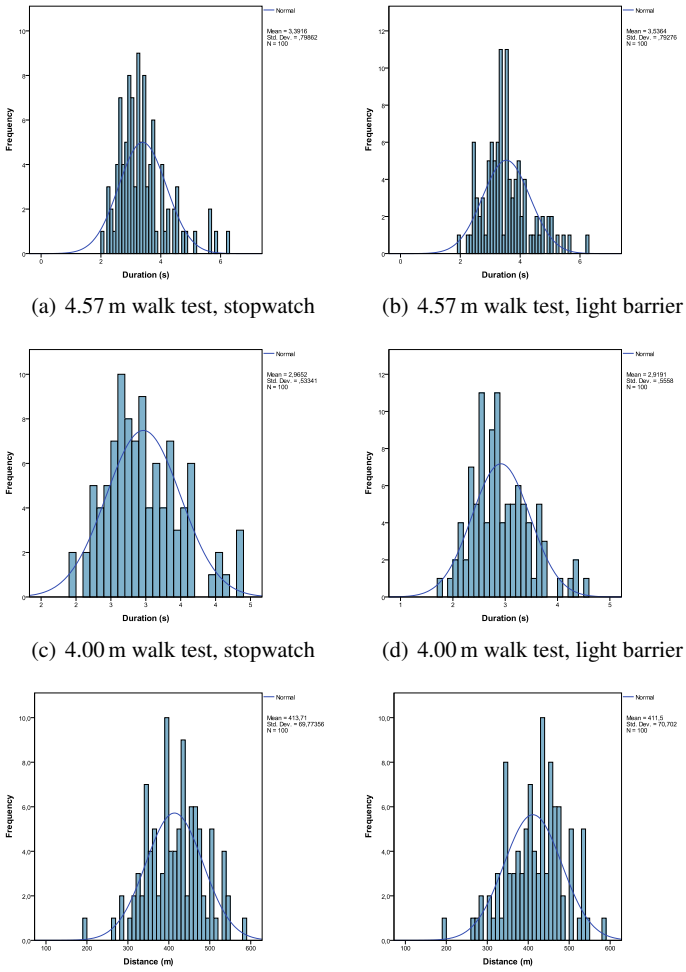
Hinman et al. [16] mentioned that participants ascended and descended stairs at an average speed of 1.3 steps per second.

The analysis of the validity and the determination of the sensitivity and specificity is demonstrated with the example of the 4.57 m walk test. In order to assure the validity of both, the automatic and the manual measurement, results of 100 participants are compared regarding to their correlation and difference. Therefore, the first 100 error-free measurements are analyzed.

Results

According to rule of thumb of the central limit theorem the chosen sample size of n=100 indicates a normal distribution of the samples. This assumption is confirmed by the sample's normal distribution within the histograms and the q-q-plots, shown

in Figure 5 and Figure 6, respectively. Therefore, all analyzed tests (4.57 m, 400 m and 6 min) are normally distributed.

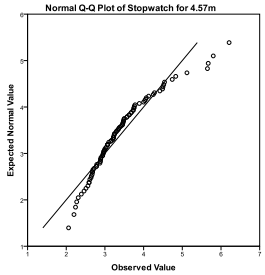


(a) 4.57 m walk test, stopwatch (b) 4.57 m walk test, light barrier

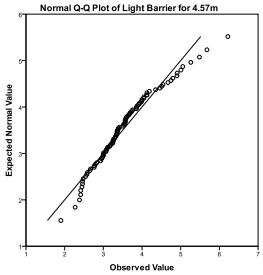
(c) 4.00 m walk test, stopwatch (d) 4.00 m walk test, light barrier

(e) 6 min walk test, stopwatch (f) 6 min walk, light barrier

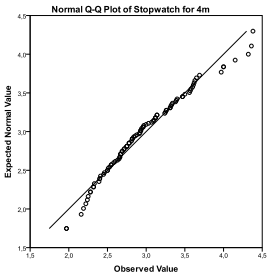
Fig. 5 Histograms of 4.57*m*, 4.00*m* and 6 min walk test for stopwatch and light barrier measurements.



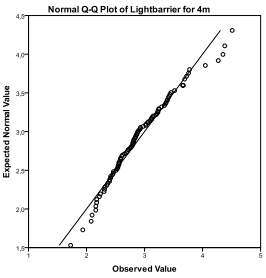
(a) 4.57 m walk test, stopwatch



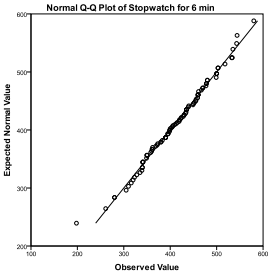
(b) 4.57 m walk test, light barrier



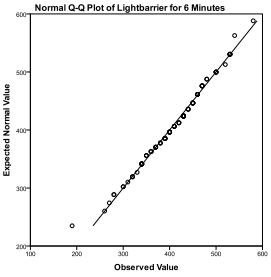
(c) 4.00 m walk test, stopwatch



(d) 4.00 m walk test, light barrier



(e) min walk test, stopwatch



(f) 6 min walk, light barrier

Fig. 6 Normal q-q-plots of 4.57m, 4.00m and 6 min walk test for stopwatch and light barrier measurements.

Table 3 Analysis of 4.57 m walk test.

Model	B	Std. Error	Beta	t	Sig.
(Constant)	70,177	22,09		3,177	0,002
light barrier	0,841	0,053	0,852	15,914	0
Tester2	-1,365	9,483	-0,008	-0,144	0,886
Tester3	-8,397	8,822	-0,054	-0,952	0,344

Table 4 Analysis of 4.00 m walk test.

Model	B	Std. Error	Beta	t	Sig.
(Constant)	0,26	0,114		2,284	0,025
light barrier	0,914	0,036	0,952	25,337	0
Tester2	0,099	0,048	0,077	2,047	0,043
Tester3	0,06	0,047	0,05	1,265	0,209

Table 5 Analysis of 6 min walk test.

Model	B	Std. Error	Beta	t	Sig.
(Constant)	70,177	22,09		3,177	0,002
light barrier	0,841	0,053	0,852	15,914	0
Tester2	-1,365	9,483	-0,008	-0,144	0,886
Tester3	-8,397	8,822	-0,054	-0,952	0,344

The analysis shows that, due to the statistical significance values, there is a correlation between the stopwatch and light barrier measurements for the 4.57 m, 4.00 m SPPB and the 6min walk test. Therefore, the results for the stopwatch measurement can be predicted on the basis of the light barrier measurements. The correlation can be described for the 4.57 m walk test by following regression line:

$$t_{stopwatch} = 0.911 \cdot t_{lightbarrier} + 0,135 \tag{4}$$

It has been further examined whether the different study nurses or physical therapist have an influence on the measured results. Three different experimenter conduct the functional assessments In our study. There was no influence on the measurement for the 4.57 m and the 6 min walk test. But the analysis shows that study nurse 2 has a low influence for the 4.00 m walk test.

Table 6 shows the classification for 100 participants on the basis of the cut-off values [14] for the 4.57 m walk test. One senior of the 100 participants is classified as frail by the experimenter and the measuring system. None of the participants was false classified as frail by the measuring system. Therefore, the sensitivity is determined

Table 6 Classification of the participants in frail and not-frail at the 4.57 m walk test on the basis of the cut-off values for this test.

	frail	not-frail	sum
frail	1	0	1
not-frail	0	99	99
sum	1	99	100

as 100% and the specificity as 100%. The kappa-coefficient κ is a measure of agreement between two sources, which is measured on a binary scale (i.e. category frail / not frail). A κ-coefficient between 0,80 and 1 characterizes a very good agreement and between 0.60 to 0.79 a good agreement. For the $4.57m$ walk test the result for κ is 1. Table 7 shows the calculation for the assessment items supported by light barriers. Each light barrier supported assessment item performs with a good sensi-

Table 7 Validity of the light barrier measurement system.

test	sensitivity	specificity	κ	t-test	correlation
Frailty (4.57m)	100%	100%	1	0.2	0.9
SPPB (4m)	100%	100%	1	0.55	0.93
6 min walk test	100%	95.2%	0,64	0.83	0.85

tivity. The specificity and the κ-coefficient at the $6min$ walk test show no excellent conformity with respect to the gold standard. The reason for the false categorization of the participants can be attributed to the measuring setup. The light barriers are installed on the corridor with a distance of $10m$. Due to this fact the accuracy of the measurement is about $\pm 10m$.

Optimization of measurement system

To improve the specificity and reliability of our system, consistency checks of the results are performed to identify incorrect measurements. If measured data passes a threshold value, because of too high or too low results, these measurements are automatically categorized as false measurement. In addition a redundant system records all light barrier signals during the whole assessment, so the results of each test can be reconstructed afterwards, especially for missing start and stop signals by the remote control. In addition to acoustic signals at the start and end of the tests, an optical control system is implemented. Different colors show the status of the test in the graphical user interface of the measuring program and the experimenter can check if the test didn't start, didn't stop or which light barrier wasn't passed by the participants.

4 Applicability of the devices for ambient home-assessments

In this section we want discuss the integrability of the applied ambient measuring devices at home. To measure indoor walking speed, light barriers can be used [19]. They can be easily integrated at home. The aTUG system is an unobtrusive device for measuring sit-to-stand cycles in daily life or to also analyze the walking speed by laser rangefinder. Consequently , the aTUG system could replace normal chairs and measure these parameters during activities of daily living of the elderly. The force plate allows an evaluation of balance and strength. It is possible to integrate such a plate in the floor for example at frequently used places in home. Furthermore force plates are able to detect falls.
Beside the analyzes at home, consideration of outdoor activities is also important to achieve a high degree of significance to the functional status of older adults. Especially endurance measurements often take place outside.
Therefore, new technical developments resulted in devices such as inertial units or sensors for vital signs, which are well-suited for identification of risks and for interventions [20]. Next to highly accurate acceleration measuring devices like the sensor belt used in this study, other devices like smart phones, smart watches, pedometers or GPS-loggers are possibilities for detecting indicators of functional decline in future. Such devices are affordable, so deployment in larger groups is not hindered by costs. They are easy to use in daily life and can be used also by technically less experienced people over a longer period of time [21]. They are reliable and precise, so information gathered from monitoring of behavior and vital parameters is a valid basis for feedback and interventions.

5 Discussion and further work

This paper introduces a technology supported measurement system for a clinical functional assessment and evaluates its correctness in terms of correlation and difference to valid measurements.
The system consists of a portable force plate, the aTUG system, a hand-grip dynamometer, a stadiometer and a bio-impedance measuring device as well as a light barrier measuring system. The light barrier system shows a high sensitivity and the results are in agreement to the valid stopwatch measurements, set as gold standard.
A benefit of light barriers compared to the technology is the objective and equal measurement. If several study nurses respectively physical therapists perform an assessment, the potential different reaction times of each person influence the results. Another advantage lies in the fact that the time of the turn at the end of the walking route and the associated deceleration can be excluded from the calculation of the walking speed by using light barriers.
Furthermore it is possible to get more information when using technology. The aTUG system detects the sit to stand cycle and makes detailed gait analyzes beside measuring the duration of the TUG-test. The force plate delivers force, power

and velocity values during the assessment items and allows a precision analysis of a jump action or balance tests. Due to these points technology is able to support and enhance a clinical assessment.
Beside ambient sensors a wearable sensor belt is used in this study. In further work the data of the sensor belt will be analyzed. One aim of the study is to compare and to identify the single geriatric assessment items with the sensor data of the belt and to answer the question if the sensor belt provides equal or even more information or results as a conservatively measured assessment. Maybe one week wearing this sensor belt can be engaged instead of a geriatric assessment to get the same results in the future.
The described ambient measurement devices are suitable for ambient home-assessments. In addition to the sensor belt, new technical developments resulted in devices such as smart phones, smart watches, pedometers or GPS-loggers can be probably used in future to detect indicators for functional decline or could be a valid basis for interventions.

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