Video Article

Clinical Assessment of Spatiotemporal Gait Parameters in Patients and Older Adults

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Abstract

Spatial and temporal characteristics of human walking are frequently evaluated to identify possible gait impairments, mainly in orthopedic and neurological patients[1-4], but also in healthy older adults[5,6]. The quantitative gait analysis described in this protocol is performed with a recently-introduced photoelectric system (see Materials table) which has the potential to be used in the clinic because it is portable, easy to set up (no subject preparation is required before a test), and does not require maintenance and sensor calibration. The photoelectric system consists of series of high-density floor-based photoelectric cells with light-emitting and light-receiving diodes that are placed parallel to each other to create a corridor, and are oriented perpendicular to the line of progression[7]. The system simply detects interruptions in light signal, for instance due to the presence of feet within the recording area. Temporal gait parameters and 1D spatial coordinates of consecutive steps are subsequently calculated to provide common gait parameters such as step length, single limb support and walking velocity[8], whose validity against a criterion instrument has recently been demonstrated[7,9]. The measurement procedures are very straightforward; a single patient can be tested in less than 5 min and a comprehensive report can be generated in less than 1 min.

Video Link

The video component of this article can be found at https://www.jove.com/video/51878/

Introduction

Walking is one of the most important physical activities in everyday life, and is a main determinant of the quality of life for elderly and patient populations who may present with gait deteriorations. Clinical evaluation of gait function is therefore important to reveal potential alterations induced by aging and/or neurological/orthopedic pathologies, but also to prove the functional benefits of a treatment. Different instruments have been developed for the quantitative assessment of gait parameters, *e.g.*, force plates, video-based 3D motion analysis, body-mounted accelerometers[10,11], and instrumented walkway mats or treadmills[12]. However, these systems are mainly used for research studies rather than for clinical purposes because they are complex to operate, have low accessibility, and fragile sensors.

A floor-based photoelectric system has recently been introduced, which is able to provide a valid calculation of temporal features and 1D spatial coordinates of walking steps. This measuring instrument has several advantages compared to pre-existing systems: it is easy to handle, data are collected very quickly, it is simple to create a detailed report and it is a modular system which means that the length of the system can be changed. Thus, it can be used with confidence to measure within-group changes in longitudinal assessments and between-group differences in cross-sectional comparisons. The goals of the described protocol are to focus on the equipment and its installation, and to objectively and straightforwardly describe the assessment procedures for evaluating spatiotemporal gait parameters in elderly and patient populations.

Protocol

The protocol follows the guidelines of the local human Ethics Committee in Zurich (KEK Zurich).

1. Hardware Installation (Figure 1)

1. Use two 10-m sets of floor-based bars and place them parallel to each other (and to the line of progression) to create a corridor with an inter-set distance of approximately 1 m.
   NOTE: This distance can be increased up to 8 m. Each bar has a length of 1 m and consists of 96 light diodes.
2. Make a distinction between light-transmitting (T) and light-receiving (R) units for the installation of the bars by placing the light-transmitting (T) units on the right side and the light-receiving (R) units on the left side with respect to the walking direction.
   NOTE: The first meter bars (both T and R) have silver drums. The T and R bars disposed on the remaining 9 m are all equal and interchangeable.
3. Connect all bars of a row with caps (wireless). Use 2 power supplies: one for each set of bars (T and R).

4. Connect the first R bar to the laptop with a USB cable.
5. Position the camera next to the first bar for offline verifications (*e.g.*, starting foot), and connect it to the laptop with a USB cable.
6. Put a mark 2 m before and after the beginning and end of the track.
7. Switch on the photoelectric device using the on-off switch of the first R and T bar.
8. Check that the control LEDs located on all R bars are green.
   NOTE: If so, the system is correctly positioned and testing can start; however, if one or more of the control LEDs are red the system is not correctly positioned and/or connected. Control all caps by checking that they are completely clicked into place and then turn the system off and on again.

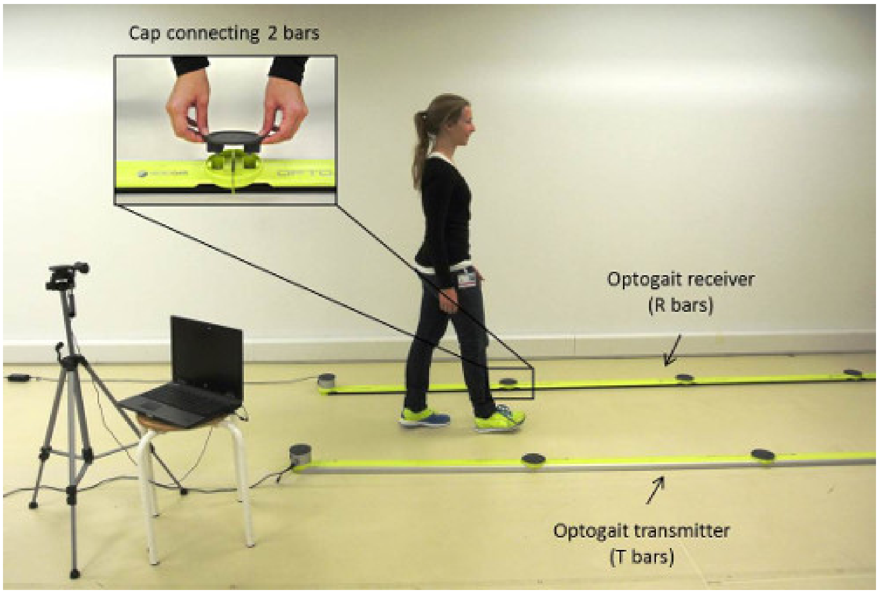


Figure 1. The photoelectric system consists of light-transmitting (T) and light-receiving (R) units that are placed parallel to each other with a distance of approximately 1 m. The camera is installed close to the start area for control purposes. The laptop is connected with USB cables to the first R bar and to the camera. Please click here to view a larger version of this figure.

2. Software Installation and Preparation of a Test

1. Load the software operating the photoelectric system from www.optogait.com/Support/Downloads. Note: This protocol is described by using the 1.8.1 version.
2. If the software is used for the first time for gait analysis create a new test as follows (otherwise proceed to step 2.3):
   1. Select *Test* then click on *Define / Modify tests.* Now click on *Gait test* and then select *Duplicate test*. Click on *Confirm* in the pop-up window so that the test is duplicated.
   2. Double click on the duplicated test to modify the name (*e.g.*, Gait Test 10 bars) and select 10 for the number of bars. Use the standard parameters for the gait test, which are presented in **Figure 2**. Finally, select *Save* to save all modifications.
3. Add a new patient to the database. Select *Patients*, click on *Insert / Modify patient*, and then click on *New patient* to enter the data. Then *Save* the data.

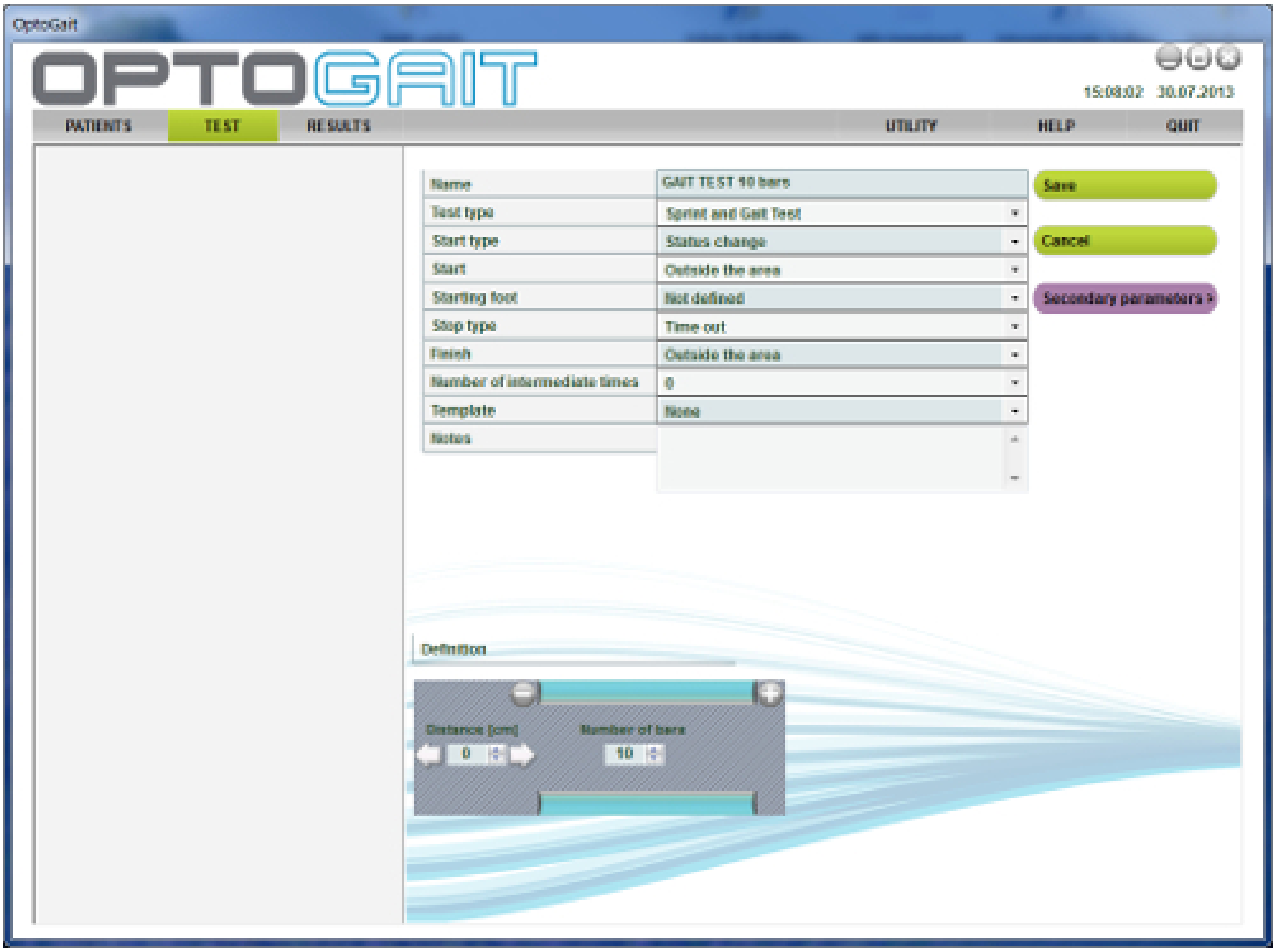


Figure 2. Standard settings for a gait test with 10 bars, as described in the present protocol. These settings have to be defined when the photoelectric system is used for the first time. In this protocol the starting foot is not defined. The system starts measuring when the patient enters the recording area and stops measuring when the patient leaves the measuring units. Please click here to view a larger version of this figure.

3. Testing Procedures

1. Always give the same instructions to the patient[13].
    1. Instruct the patient to walk with flat-soled shoes along the 10-m walkway at two different velocities: normal ("walk at a pace that is comfortable for you"), and faster than normal ("walk at a pace that is faster than you would normally walk").
    2. Ask the patient to look straight ahead during the walking trials.
    3. Ask the patient to initiate the first step with the same foot to better standardize the test conditions.
    4. Ask the patient to start walking 2 m before the first photoelectric bar and to conclude each trial 2 m after the last bar in order to maintain constant gait velocity[13].
2. Demonstrate one trial at normal velocity to the patient.
3. Request the patient to perform three familiarization trials followed by one experimental trial at each velocity. Always complete normal velocity trials first.
4. To get ready with the software, click on *Test* and then *Execute* to start the measurements with the created test.
    1. Select the patient by clicking on *Select*, choosing the patient and then clicking on *Confirm.*
    2. Select the test by clicking on *Select*, and choosing the test *e.g.*, Gait Test 10 bars. Check that only this test is selected for the measurement.
    3. Place the camera so that it can record the entire walk. Change the position of the camera while checking the live picture on the screen of your laptop.
    4. Finally, click on *Execute* again.
    NOTE: Now the software is ready to measure. As soon as the patient enters the bars, the system starts to measure and a pop-up window appears asking for the starting foot.
5. Click on the appropriate foot so that the gait parameters will be correctly calculated.
    NOTE: The camera records automatically once the test is started.

6. Save the test.

4. Data Analysis

1. Click on *Results* to display the completed trials. Then click on the arrow next to the test of interest to transfer the test from the *Test list* to the *Test analysis* section. Now click on *View* to display the selected test. Refer to the Results section for all tests performed in this study.
NOTE: A window with all test data appears (**Figure 3**). On the left side of the window there are some command buttons for activating various functions. The other part of the window presents 4 types of information regarding the current test. Each set of information can be shown/hidden using the configuration commands. From top to bottom the items are the following: video, charts displaying the results, table with numerical data, and photoelectric bars.
2. Click on *Gait data* to display a gait report (**Figure 3**).
3. Click on *Print* (a window with the report appears) to print out the report.
NOTE: The report can be printed as it is or can be modified. For the different spatiotemporal parameters, the following results are presented in the report: mean values ± standard deviation (SD) of the left and right side, coefficients of variation (CV) expressing gait variability[14,15], and percent difference between the left and the right side (asymmetry).
    1. If required, modify the report as follows: open the report as described above (step 4.3). Click on the buttons *Show* or *Hide* on the left side of the screen to adapt the presented data and charts of the report.
    2. To change the logo and/or the footer on the report, click on the respective button (*Change logo* or *Change footer*) to modify these parameters.

4. To compare two or more tests performed on different occasions, *e.g.*, before and after an intervention, select the different tests in the results section by clicking on the arrow next to the tests and then click on the *Compare* button.
NOTE: A report with the direct comparison of all parameters of the different tests is displayed.

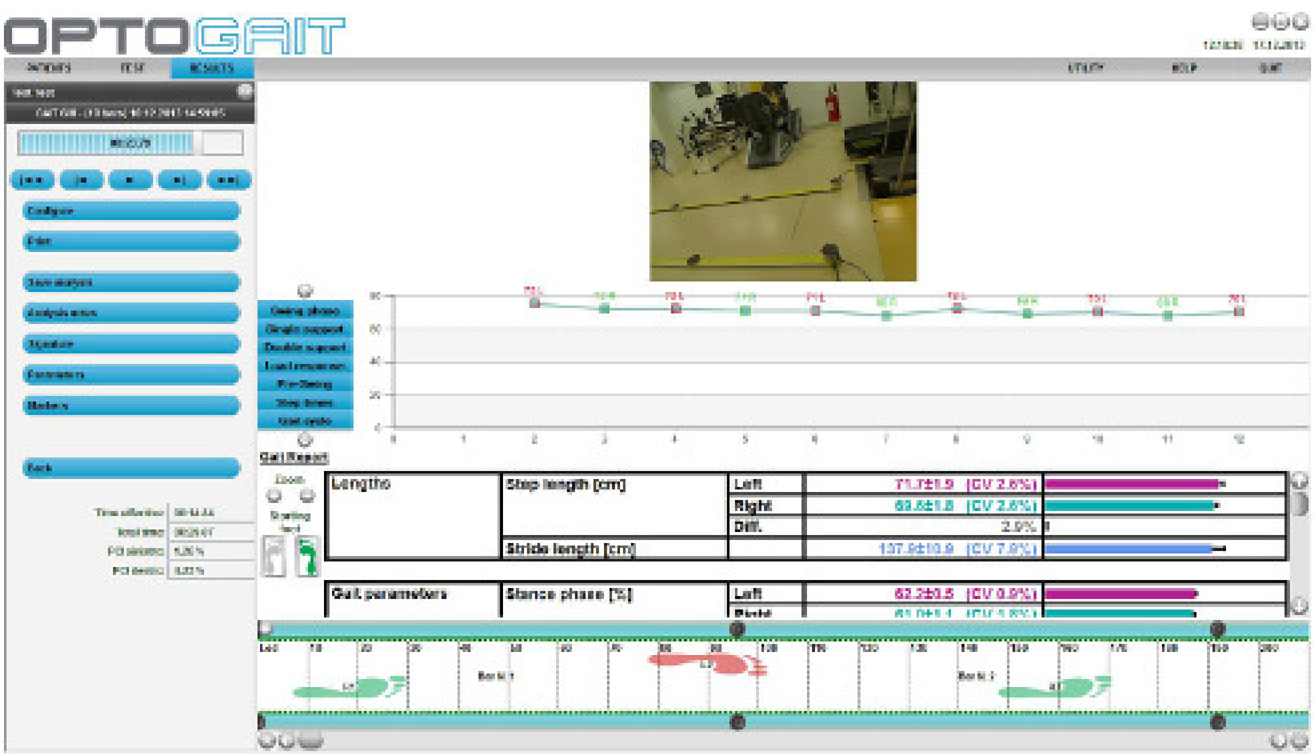


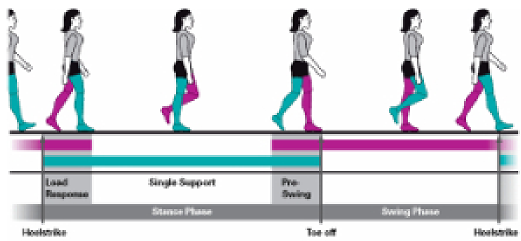
Figure 3. Screenshot of all test data. The command buttons appear on the left side of the window (*e.g.*, by clicking on *Print* a report is generated, which can be eventually modified). The other part of the window presents the following information regarding the current test, from top to bottom: video, charts displaying the results, table with numerical data, and photoelectric bars. These details can be shown/hidden using the *Configure* button on the right side. The actual view of the data can be changed by clicking on *Gait data* or *Gait report*, respectively. Please click here to view a larger version of this figure.

Representative Results

A recent study demonstrated the validity of the photoelectric system against a criterion instrument (a validated electronic walkway) for the assessment of spatiotemporal gait parameters in orthopedic patients and healthy elderly controls[7]. The same between-group differences in gait variables were detected by the two systems. Although concurrent validity was excellent, with intraclass correlation coefficients ranging between 0.933 and 0.999 ($p < 0.001$), a systematic bias ($p < 0.001$) was observed between the two measuring instruments. Stance time and cycle time were significantly longer while swing time and step length were shorter for the photoelectric system than for the electronic walkway. In the same way, walking speed and cadence were slightly (1-2%) but significantly lower for the photoelectric system.

Data from a representative report are presented in **Figure 4**. The report shows the results of a walking trial conducted at normal velocity with 12 steps (6 left and 6 right). Spatiotemporal gait parameters of this trial are presented as mean ± SD and CV for the left and right side. Furthermore the percent difference between the left and right side (Diff.) is presented. Data of the left and right side are presented in purple and turquoise, respectively. The most common gait parameters such as step length, stance phase, swing phase, single support, step time, cadence, and speed are instantaneously (on-line) calculated and presented on the screen during the actual trials (**Figure 3**). The same values are presented in the off-line gait report (**Figure 4**). Percent difference between the two sides expresses the so-called side-to-side (or bilateral) asymmetry that is a good indicator of gait recovery, *e.g.*, before and after an intervention. Recovery of symmetrical gait function is one of the primary goals in patients rehabilitation so to regain independence in daily activities. CV is used as an indicator of gait variability, which is generally increased in patients with clinically-relevant syndromes such as falling and neuro-degenerative diseases[16,17] and therefore it is a relevant outcome measure for neurological patients and for subjects with mild cognitive impairments and dementia.

Gait Report



Lengths	Step length [cm]	Left	67.3±2.8 (CV 4.2%)	
		Right	71.2±2.8 (CV 3.9%)	
		Diff.	-5.8%	
	Stride length [cm]		138.3±4.2 (CV 3.0%)	
Gait parameters	Stance phase [%]	Left	64.4±0.6 (CV 1.0%)	
		Right	62.9±1.2 (CV 1.9%)	
		Diff.	2.3%	
	Swing phase [%]	Left	35.6±0.6 (CV 1.8%)	
		Right	37.1±1.2 (CV 3.1%)	
		Diff.	-4.2%	
	Single support [%]	Left	37.6±1.1 (CV 2.8%)	
		Right	35.6±0.6 (CV 1.7%)	
		Diff.	5.4%	
	Total double support [%]		27.1±1.1 (CV 4.0%)	
	Load response [%]	Left	12.8±0.9 (CV 6.9%)	
		Right	14.0±0.5 (CV 3.3%)	
		Diff.	-8.8%	
	Pre-swing [%]	Left	14.0±0.4 (CV 2.9%)	
		Right	13.5±0.7 (CV 4.8%)	
		Diff.	3.2%	
Time parameters	Step time [sec]	Left	0.784±0.028 (CV 3.6%)	
		Right	0.790±0.012 (CV 1.5%)	
		Diff.	-0.8%	
	Gait cycle [sec]		1.569±0.028 (CV 1.8%)	
	Cadence[steps/min]		76.5±1.4 (CV 1.8%)	
Speed parameters	Speed [m/s]	Left	0.88±0.04 (CV 4.5%)	
		Right	0.88±0.04 (CV 4.5%)	
		Diff.	0.0%	
	Average speed [m/s]		0.88±0.04 (CV 4.5%)	

Figure 4. Representative gait report of a walking trail conducted at the normal velocity by an orthopedic patient. The figure on the top presents a simplified gait cycle with the different temporal gait parameters (per foot). The table presents averaged test data of consecutive steps for the selected test. For the different spatiotemporal gait parameters the following results are presented: mean ± standard deviation (SD) for left and right side, coefficient of variation (CV) for left and right side, and percent difference (Diff.) between the left and right side. Please click here to view a larger version of this figure.

Discussion

The protocol presented here can be used to evaluate spatial and temporal gait parameters of patients (orthopedic, neurological, cardiorespiratory, etc.) and healthy older adults with a recently-introduced photoelectric system. The total length and width of the system can be modulated depending on the available space and budget. The estimated cost (in Europe) is approximately 2,800 USD per meter for a 10-meter system and the minimum recommended length is 3 meter for floor-based gait analysis. A new feature of the photoelectric system has also been recently introduced, which consists in closing the corridor with two additional bars that are positioned perpendicularly to T and R bars, thereby creating a sort of grid that allows calculation of 2D footfall patterns. Additionally, only the two first-meter bars can be used for treadmill-based gait analysis, even though this would require a validation.

Before starting the measurements it is important to verify that all the bars are properly connected; this is facilitated by the red/green control LEDs disposed on each photoelectric bar. Another critical step is the definition of the starting foot, which has to be selected at the beginning of each test. In case the wrong side is selected, offline modifications can be made at any time (open the appropriate test and select *Gait report,* then change the foot), also after having verified the starting foot (and any other eventual doubt) on the video.

The main limitation of this protocol is the use of self-selected gait velocities (normal and faster than normal), because all the spatiotemporal gait parameters are considerable affected by the walking velocity[18]. An alternative option would be to impose a fixed gait speed to all subjects by means of a metronome (*e.g.*, at 4 km/h). The validity of this approach is nevertheless uncertain as not all the patients can walk at a given velocity and/or maintain a fixed gait speed. An important limitation of the photoelectric system is the height of diodes with respect to the floor (3 mm). This instrument slightly overestimates stance time and underestimates swing time compared to floor-integrated instruments (*e.g.*, electronic walkways or force plates) because the diodes detect rearfoot loading and forefoot unloading 3 mm above floor level (see **Figure 3A** in reference 7)[7]. Due to this limitation the system can only provide valid data for subjects who are able to raise sufficiently their feet during walking and who have a step length longer than their foot length[7]. This could represent a problem for the evaluation of gait variables in some seriously-impaired neurological patients.

Since this photoelectric system is very simple to operate and valid data can be quickly collected and easily organized into a comprehensive report, this is a potentially useful system for clinical assessment of spatiotemporal gait variables in patients and older adults. Clinicians could, in fact, implement these assessments in routine physical examinations with the objectives to detect gait disorders and/or to monitor patient progress following an intervention.

Disclosures

The authors have nothing to disclose.

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