PROSTHETICS/ORTHOTICS/DEVICES

The Validity and Reliability of the GAITRite System's Measurements: A Preliminary Evaluation

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ABSTRACT. McDonough AL, Batavia M, Chen FC, Kwon S, Ziai J. The validity and reliability of the GAITRite system's measurements: a preliminary evaluation. Arch Phys Med Rehabil 2001;82:419-25.

Objective: To compare the concurrent validity and reliability of the GAITRite™ computerized gait analysis system with validated paper-and-pencil and video-based methods.

Design: Within-groups, repeated-measures design.

Setting: Research laboratory in a physical therapy education program.

Participant: One healthy woman, age 27 years.

Interventions: A subject walked across the walkway of the GAITRite system at various walking rates and degrees of step symmetry for 2 of the 3 analyses. Paper placed over the walkway enabled concurrent paper-and-pencil analysis. The subject was concurrently videotaped from the side. For the other analysis, a stride simulator with known step and stride lengths was applied to the walkway to simulate 2 steps and 1 stride.

Main Outcome Measures: Cadence, walking speed, right and left step and stride lengths, and right and left step times.

Results: Excellent paper-and-pencil and GAITRite correlations (intraclass correlation coefficient [ICC] > 95) for spatial measures and excellent video-based and GAITRite correlations (ICC > 93) for temporal measures were found. GAITRite measures of step lengths and times were reliable in both walkway center and left-of-center measurements.

Conclusions: Based on this data, GAITRite is a valid and reliable tool for measuring selected spatial and temporal parameters of gait.

Key Words: Gait; Rehabilitation; Reproducibility of results; Walking.

TEMPORAL AND SPATIAL (linear) gait parameters have been measured by various methods, including paper-and-pencil tests,[1,2] electronic foot switches,[3] and video-based analysis.[4] Most methods are labor-intensive, time-consuming, and otherwise inefficient for collecting valid and reliable data. Paper-and-pencil methods require therapists to chalk or ink patients' soles and heels to make an imprint as they walked along a paper walkway. Footfall imprints are subsequently measured with a measuring tape. A stopwatch used to measure overall trial time (ie, from start to finish lines) often requires the timer to estimate when the subject broke the plane of the start and finish lines, which introduces potential error in temporal measures. Direct temporal and linear measures have been used with derived formulae.[1] In some cases, foot switches tethering the subject to a recording device have been attached to the patient's heels to document footfalls electronically.[5]

McDonough and Nelson[4] measured linear gait parameters directly on a video monitor from a videotaped record of walking trials. With a stop-action videocassette recorder/player (VCR) that permitted frame-by-frame analysis, they calculated a scale factor from a ratio of image-to-actual lengths of a videotaped reference structure. They then applied the scale factor to linear measures taken directly (by caliper) from a monitor. They measured time with the VCR's frame counter; infrared beam sensors lit up when the subject broke the plane of the start and finish lines.

Portable (flexible) walkways with embedded, pressure-sensitive switches reduce the labor-intensive and time-consuming aspects of measuring temporal and linear gait parameters. The GaitMat[a] walkway has 2 rows of 256 pressure-activated switches embedded in a mat scanned by a dedicated microprocessor.[6] Data are processed by a second IBM compatible computer by using GaitMat software. GaitMat II is an updated version of the GaitMat system that has improved on the previous design by eliminating the proprietary microprocessor.[7] Data are now collected and processed by the same IBM compatible computer.[b] The new system scans the embedded sensors at a faster rate and can differentiate left from right footfalls, which the original system could not.

Recently, the GAITRite™ system[c] was developed to measure and record temporal and spatial parameters of gait by using a walkway approximately 3 meters long with grids of embedded, pressure-sensitive sensors connected to a personal computer. As a subject walks across an instrumented mat, electronic recordings of each footfall are made and stored as a computer file. Temporal and spatial parameters of gait are automatically calculated and displayed and can be printed after the subject completes a trial. The GAITRite system offers the obvious advantage of automating what has historically been tedious and labor-intensive measurements of gait parameters. The present study assessed the GAITRite system's ability to validly and reliably measure selected temporal and spatial parameters of gait, comparing the system's performance against 2 validated gait analysis methods: paper-and-pencil[1,8] and video.[4]

METHODS

Subject

A healthy 27-year-old woman with equal leg lengths participated in gait analyses that required a human subject. She was asked to walk at randomly selected velocities and degrees of step symmetry. She gave informed consent as approved by the

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The GAITRite System

Embedded sensors in the GAITRite mat are triggered when mechanical pressure is applied. Sensor activation is a physical event that occurs irrespective of the source of the pressure. Whether the pressure is from foot contact of a normal subject or a subject with a functional impairment, or even from contact by a mechanical device, sensors (or groups of sensors) will respond the same. Persons with gait impairments often have temporal disturbances of the gait sequence (eg, the time between heel contact and foot flat during stance). The GAITRite software calculates elapsed time after sensor activation; it does not rely on derived formulas to document temporal events. The time span between sensor activations is the same whether the source of the activation is mechanical force from a normal subject or from an individual with a disability. We were confident that the system's ability to measure temporal and spatial gait parameters in a subject without disabilities would approximate its function in persons with gait disturbance. Because sensor activation in GAITRite between trials is not affected by time or the means by which the force is applied, having a single subject emulate gait disturbances by varying gait speed and degrees of step symmetry was warranted.

Analyses

We conducted 3 analyses to evaluate the GAITRite system. (1) To test concurrent validity between the methods, we measured temporal and spatial parameters of gait concurrently with the GAITRite system, the paper-and-pencil method, and the video-based method as the subject walked at various rates. The parameters we evaluated were walking speed, cadence, step length, and step time. (2) We assessed how reliably the GAITRite system accurately measured spatial parameters of gait. We compared step and stride lengths measured by GAITRite with linear measures from a stride simulator that was constructed with fixed step and stride lengths. With the simulator providing the mechanical force along the GAITRite's pressure-sensitive walkway, we compared measures taken from the center and along 1 edge of the walkway. (3) We assessed how reliably the GAITRite system measured right and left step times of the subject, walking at 3 rates, compared with video-based methods.

Equipment setup. Figure 1 shows the equipment setup used to perform concurrent gait analysis by GAITRite, video, and paper-and-pencil methods. The GAITRite system has 2 main components: a pressure-sensitive mat (61 × 366cm) and a personal computer (PC). The mat is composed of a series of sensors, 1.27cm on center, organized in a 48 × 288 grid pattern sandwiched between 2 layers of vinyl. The mat gives the visual impression of a carpet runner. For the first analysis, a paper walkway was placed over the mat to record footfalls by the pencil-and-paper method concurrently with GAITRite recordings. The paper walkway was not used for the second or third analyses. Data from the triggered sensors are collected by on-board processors connected in series and fed to the computer through a serial port (19,200 baud). GAITRite software (version 2.2) running on the Windows 95[d] operating system processed the data and provided mean temporal and spatial parameters and a functional outcome score. The sampling rate was 24Hz. The system also permitted us to analyze individual steps or strides. Data were organized in on-screen tables and printed out as hard copy.

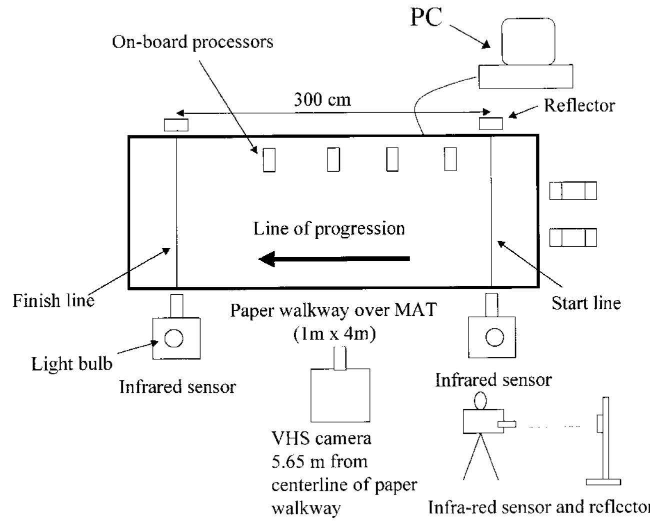

Fig 1. Equipment setup for measuring gait parameters with the GAITRite mat and PC, paper-and-pencil, and video methods.

A VHS-format Panasonic video camera[e] (model AG-450) operating at a sampling rate of 30 frames per second was used to videotape walking trials during the first and third analyses. The video camera was mounted on a tripod and positioned midway between the start and finish lines of the walkway with the camera's field of view perpendicular to the long axis of the walkway. The plane of the camera's shutter was located 5.65 meters from the centerline of the walkway. This distance ensured that light bulbs, attached to 2 infrared sensors and aligned with the start and finish lines, could be seen in the camera's viewfinder. In the first analysis, the subject stood at the start line with her toes just behind the line. An infrared reflective beam[f] (model 49-307) was aligned with the start and finish lines. A light bulb was wired to the connector panel of the device and switched so that when the infrared beam was broken by the subject's advancing lower leg, the light bulb would light to document the start and end of each walking trial. Videotaped trials were analyzed on a Panasonic VCR[e] (model AG 7350) fitted with a cog-wheel control that permitted frame-by-frame advancement of the videotape.

Concurrent measures of step time and length, walking speed, cadence. A paper sheet approximately 1 meter wide and 4 meters long and marked with start and finish lines 300cm apart was taped over the GAITRite walkway. The heels and toes of the subject's shoes were rubbed with blue carpenter's chalk so that imprints of each footfall were made as the subject walked.[1] The subject performed 8 trials at various walking speeds and degrees of step symmetry. An investigator timed each trial with a hand-held digital stopwatch, pressing the start button when the light bulb at the start line lighted and pressing the stop button when the light bulb at the finish line lighted. Overall walking time was recorded to the nearest one tenth of a second. Step-length measures were made directly on the imprinted paper sheet by using a metric measuring tape.[1] The straight-line distances between the rear edge of each heel between steps (ie, consecutive contralateral heel strikes) were measured and recorded to the nearest one tenth of a centimeter. Footfalls that landed on the start or finish lines were excluded. The footfalls were counted and the cadence was calculated for each trial. Walking speed was calculated from the known distance and calculated trial times. Right and left step times were calculated by using the formula:

$$\text{Step time (s)} = \frac{\text{step length (cm)}}{100\text{cm/m} \times \text{walking speed (m/s)}}$$

Cadence, walking speed, step length, and step time reports were printed from GAITRite software for subsequent comparisons. Each trial was videotaped. Walking times and step times were measured by using a frame-counting method. For overall walking time, the VCR was used to document when the subject's lower leg broke the beams of infrared sensors at the start and finish lines, respectively. The number of frames between the 2 events was counted and overall walking time was calculated by multiplying the number of frames by a conversion factor of 33.4ms/frame. A similar method was used to measure right and left step times. In this case, contralateral heel strikes were documented on the videotape, the number of frames were counted, and the same conversion factor was applied. Cadence was calculated by counting the number of steps during each trial, and dividing this number by the overall walking time (steps/min). Walking speed was determined by dividing the trial distance (300cm) by overall trial time expressed as centimeters per second.

Step and Stride Length Measures

Equipment. To assess the GAITRite system's ability to reliably measure step and stride lengths, we constructed a device that simulated 3 consecutive steps (fig 2). The outlines of the soles of 2 right and 1 left shoe were cut from a piece of stiff plywood. The 3 soles were permanently mounted on 2 wooden struts to simulate the foot placements needed to take a left and right step and 1 right stride each time the device was applied to the mat. The heel-to-heel distance between the first right and left sole was 64.8cm and the distance from the left sole to the second right sole was 49.4cm. The second heel-to-heel distance was intentionally made shorter than the first to simulate asymmetrical foot placement.

Procedure. The GAITRite system software only provides data when a minimum of 4 consecutive footfalls are recorded. The stride simulator only simulated 3 footfalls. To ensure that the GAITRite system would be triggered and record data, 2 investigators, positioned next to each other, knelt beside the mat. When the software signaled that data could be collected, the first investigator pressed the stride simulator onto the mat by using a heel-toe action, applying the soles in a sequence that simulated a stepping action. When the third footfall was applied, the investigator handed the device to the second investigator who reapplied the device in the same way, simulating 6 footfalls and, thus, triggering the GAITRite software. Because the linear distance between the last footfall applied by the first investigator and first footfall applied by the second investigator could not be standardized, the second set of footfall data was ignored. Thus, the GAITRite software was triggered with its required minimum number of footfalls, and we obtained usable measures of the first set of simulated steps. Ten trials were performed and the data averaged for left and right steps and 1 right stride.

To assess the GAITRite system's ability to take measurements from different portions of the walkway, we repeated the procedure twice. The first set of simulated steps was applied along the centerline of the mat. The second set was applied to the left of the centerline of the walkway, midway between its centerline and its left edge.

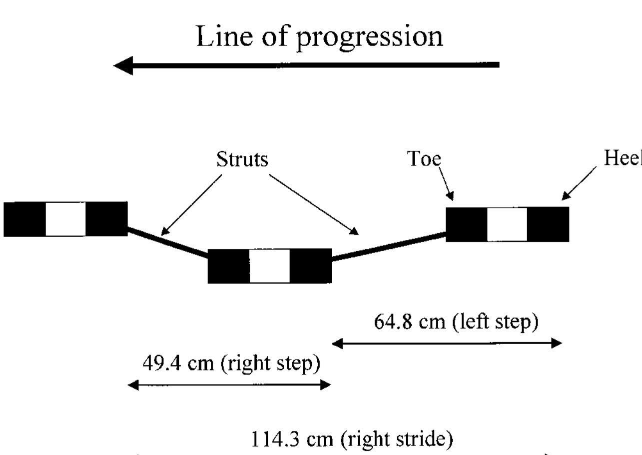

Fig 2. Superior view schematic of the stride simulator. The device simulated 2 steps and 1 stride, with the second step intentionally shorter than the first to simulate an asymmetrical second step.

Step Time Measures

To assess the GAITRite system's ability to measure reliably temporal parameters of gait, we compared right and left step times by using the GAITRite and video-based methods at 3 walking rates: (1) preferred, (2) less than preferred, and (3) faster than preferred. The subject stood 36.2cm from the leading edge of the walkway to ensure that the first footfall occurred after the start line. Step times were measured with the video frame counting method described earlier. Right and left step times measured by the GAITRite system were printed from its software.

Data Analysis

For the concurrent measures analysis, we used intraclass correlation coefficients (ICCs 2, 1) to assess the agreement among temporal and spatial parameters of gait measured by the GAITRite system, video-based, and paper-and-pencil methods. In the second analysis, assessing the GAITRite system's ability to measure step and strides reliably, the stride simulator, against which GAITRite was compared, had fixed linear dimensions. Thus, by definition, no between-trials variability existed for step and stride lengths and the data could not satisfy the assumption of normality.[9] We assumed that calculated ICCs, the preferred method for assessing reliability, would be deceptively low and we, therefore, used paired Student's *t* tests to determine if significant differences existed between the mean step and stride lengths measured by GAITRite and the actual step and stride lengths of the fabricated device. The alpha level was set at .05. For the right and left step times comparison, we used ICC calculations to determine the agreement between step times measured by the GAITRite system and video-based methods.

RESULTS

Sampling Rates: GAITRite Versus Video-Based Methods

The sampling rates of the GAITRite system and video camera used in the video-based method of analysis were 30Hz and 24Hz, respectively. Direct comparisons of data derived from both methods were performed without compensatory calculation to (time) synchronize the data sets. The absolute difference in sampling rates was small and, thus, represented a tolerable margin of constant error. The average latency between the onset of the infrared beam at the start point of each trial and the

Table 1: Results of Gait Analysis Performed Concurrently by 3 Methods: Paper-and-Pencil (PP), Video (VB), and GAITRite (GR) System

	Walking Speed (cm/s)			Cadence (steps/min)			Mean Step Length (cm)						Mean Step Time (s)					
							Right			Left			Right			Left		
Trial Description	PP	VB	GR	PP	VB	GR	PP	VB	GR	PP	VB	GR	PP	VB	GR	PP	VB	GR
1 Fast	154	190	165	116	111	113	85.00	119.12	85.84	88.43	117.54	89.33	0.55	0.45	0.48	0.57	0.53	0.56
2 Step-to	46	57	41	76	73	76	69.53	106.42	76.05	9.53	−4.23	−2.30	1.51	0.98	1.06	0.21	0.52	0.58
3 Preferred	111	139	127	117	113	108	68.75	52.42	69.08	70.00	64.42	71.50	0.62	0.55	0.56	0.63	0.60	0.55
4 Slow	82	101	89	86	82	85	60.93	49.87	60.57	62.50	62.52	64.21	0.74	0.69	0.70	0.76	0.73	0.70
5 Wide base	57	72	68	68	67	77	60.32	77.67	54.46	59.37	64.80	53.09	1.06	0.81	0.76	1.04	0.81	0.80
6 Narrow base	48	64	57	72	75	77	40.41	58.61	40.36	48.54	67.47	48.26	0.84	0.78	0.76	1.01	0.84	0.80
7 Toe-in	53	68	58	80	79	77	43.95	70.05	43.95	52.29	75.10	48.13	0.83	0.72	0.78	0.98	0.82	0.79
8 Toe-out	55	73	61	75	73	75	48.54	77.19	48.66	48.95	56.80	49.08	0.88	0.77	0.78	0.89	0.78	0.82

point of heel contact that triggered data collection by the GAITRite system was slightly more than 84ms (between 2–3 video frames). Synchronizing the GAITRite system with the video-based method was necessary only to the extent that the investigators could be assured that the footfall being studied was the same by using each method.

Concurrent Measurement Analysis

Table 1 shows comparative data for the 3 gait analysis methods. Walking speed and cadence measurements are the single parameter measurement for each of the 8 gait patterns. For example, when the subject was asked to walk at a slower than preferred rate, her walking speed, calculated by the paper-and-pencil, video-based, and GAITRite methods was 82, 101, and 89cm/s, respectively.

Step lengths and step times are means of footfalls for the 3 methods. The number of footfalls used to calculate means varied depending on walking speed and/or the gait pattern. For example, to calculate mean left and right step lengths when the subject was asked to walk at her preferred rate (111cm/s), 2 right and 1 left footfalls occurred between the start and finish lines of the walkway. When the subject walked at a slower than preferred rate (82cm/s), 2 right and 2 left footfalls were documented. In some cases, the gait pattern inherently impacted walking speed. When the subject walked by using a step-to gait, walking speed slowed substantially to 46cm/s. Accordingly, 5 left footfalls and 4 right footfalls occurred.

ICCs (2, 1) comparing paper-and-pencil versus GAITRite, and video versus GAITRite were calculated on the single parameter measurement for all 8 walking patterns, whereas those for right and left step lengths and step times were calculated on mean values for all 8 walking patterns.

Stride Simulator

For the stride simulator analysis, we compared the reliability of the GAITRite system's ability to measure spatial measures (fixed step and stride lengths) with the paper-and-pencil method (table 2). Data were measured along the walkway's centerline (32.5cm from the edge opposite the processors) and to its left of center. The first and second step lengths ± standard deviations (SDs) of the stride simulator, which simulated 2 steps and 1 stride, were 64.8 ± 0.0cm and 49.4 ± 0.0cm, respectively, whereas the stride length was 114.2 ± 0.0cm. For the walkway centerline (C trials) data, the first and second mean step lengths measured by the GAITRite system were 64.9 ± 0.6cm and 49.3 ± 0.6cm, respectively, and the mean stride length was 114.2 ± 0.3cm. For the GAITRite data collected left of the walkway center (LOC trials), mean first and second step lengths were 64.9 ± 0.5cm and 49.3 ± 0.6cm, respectively, and the stride length was 114.3 ± 0.3cm.

For the third analysis, assessing step time, we compared data collected by the GAITRite system with that measured by the video-based method (table 3) because the first analysis findings had suggested that the video-based method measured temporal measures more accurately. The GAITRite measures for right and left step times were close to those from the video-based system, and ICC calculations would show how closely the 2 measurement methods correlated.

Validity and Reliability of the GAITRite Measures

We first calculated ICCs (1, 2) of the GAITRite system's measures of walking speed, cadence, step length, and step time compared with concurrent measurements by paper-and-pencil and video-based methods (table 4A). Correlations between GAITRite and paper-and-pencil measures were excellent on spatial measures (right step length, ICC = .97; left, ICC = .99), whereas correlations for temporal measures (tables 1, 4) were fair (right step time, ICC = .67; left, ICC = .61). Correlation was excellent for walking speed measures (ICC = .96) and poor for cadence measures (ICC = .32).

An opposite pattern emerged in the comparisons with video-based methods. Correlations between GAITRite and video-based measures of step times were excellent (right step time, ICC = .97; left, ICC = .95), whereas those for step length were weaker (right, ICC = .44; left, ICC = .85). Excellent correlations were found for GAITRite and video for walking speed (ICC = .95) and cadence (ICC = .96).

We used paired Student's *t* tests to compare data from the stride simulator analysis (table 4). With alpha set at .05, we found no significant differences between spatial measures made by the GAITRite system and the paper-and-pencil methods. This finding was expected because those 2 methods had also correlated in the spatial measures made concurrently during the subject's walking trials (see table 1).

At 3 walking rates (identified by the subject as preferred, slower than preferred, faster than preferred), we found excellent ICCs of mean right and left step times (.94 and .99, respectively) between GAITRite and video-based methods (table 4).

DISCUSSION

Historically, temporal and spatial parameters of gait have been measured by various methods including observational analysis,[8] paper-and-pencil tests,[10-12] cinematic[13] and video analysis,[4] computer-assisted analysis,[14] and printed circuit boards.[15] Although most of these gait analysis methods have

Table 2: Simulator Stride Length: Differences (cm and %) in GAITRite (GR) and Simulator (SIM) Measures for Center-of-Walkway and Left-of-Center Trials

C Trials	GR Step 1 (cm)	SIM Step 1 (cm)	Difference cm	Difference %	GR Step 2 (cm)	SIM Step 2 (cm)	Difference cm	Difference %	GR Stride (cm)	SIM Stride (cm)	Difference cm	Difference %
1	64.9	64.8	0.1	0.2	49.7	49.4	0.3	0.6	114.6	114.2	0.4	0.3
2	64.6	64.8	0.2	0.3	49.7	49.4	0.3	0.6	114.3	114.2	0.1	0.1
3	64.7	64.8	0.1	0.2	49.8	49.4	0.4	0.8	114.5	114.2	0.3	0.3
4	65.6	64.8	0.8	1.2	48.7	49.4	0.7	1.4	114.4	114.2	0.2	0.2
5	64.8	64.8	0.0	0.0	49.7	49.4	0.3	0.6	114.7	114.2	0.5	0.4
6	65.8	64.8	1.0	1.5	48.2	49.4	1.2	2.5	114.1	114.2	0.1	0.1
7	64.8	64.8	0.0	0.0	49.7	49.4	0.3	0.6	114.6	114.2	0.4	0.3
8	64.7	64.8	0.1	0.2	49.5	49.4	0.1	0.2	114.2	114.2	0.0	0.0
9	65.7	64.8	0.9	1.4	48.6	49.4	0.8	1.6	114.4	114.2	0.2	0.2
10	63.7	64.8	1.1	1.7	49.7	49.4	0.3	0.6	113.5	114.2	0.7	0.6
Mean	64.9	64.8	0.4	0.7	49.3	49.4	0.5	1.0	114.3	114.2	0.3	0.3
SD	0.6	0.0	0.5	0.7	0.6	0.0	0.3	0.7	0.3	0.0	0.2	0.2
LOC Trials	**GR Step 1 (cm)**	**SIM Step 1 (cm)**	**Difference cm**	**Difference %**	**GR Step 2 (cm)**	**SIM Step 2 (cm)**	**Difference cm**	**Difference %**	**GR Stride (cm)**	**SIM Stride (cm)**	**Difference cm**	**Difference %**
1	64.6	64.8	0.2	0.3	49.8	49.4	0.4	0.8	114.4	114.2	0.2	0.2
2	64.6	64.8	0.2	0.3	48.7	49.4	0.7	1.4	113.4	114.2	0.8	0.7
3	64.6	64.8	0.2	0.3	49.7	49.4	0.3	0.6	114.3	114.2	0.1	0.1
4	64.9	64.8	0.1	0.2	49.7	49.4	0.3	0.6	114.6	114.2	0.4	0.3
5	64.5	64.8	0.3	0.5	49.8	49.4	0.4	0.8	114.5	114.2	0.3	0.3
6	64.8	64.8	0.0	0.0	49.9	49.4	0.5	1.0	114.6	114.2	0.4	0.3
7	65.7	64.8	0.9	1.4	48.6	49.4	0.8	1.6	114.3	114.2	0.1	0.1
8	64.5	64.8	0.3	0.5	49.9	49.4	0.5	1.0	114.4	114.2	0.2	0.2
9	65.6	64.8	0.8	1.2	48.6	49.4	0.8	1.6	114.2	114.2	0.0	0.0
10	65.6	64.8	0.8	1.2	48.7	49.4	0.7	1.4	114.3	114.2	0.1	0.1
Mean	64.9	64.8	0.4	0.6	49.3	49.4	0.5	1.1	114.3	114.2	0.3	0.2
SD	0.5	0.0	0.3	0.5	0.6	0.0	0.2	0.4	0.3	0.0	0.2	0.2

proved to be valid and reliable, many are time-consuming, cumbersome, and awkward to use. Some proprietary systems[16] are not routinely available to clinicians and researchers. The GaitMat recording system consisted of a 3.8-meter long walkway embedded with pressure-sensitive switches that were scanned by a dedicated microprocessor and used to measure temporal and spatial parameters of gait.[17] Although less cumbersome and easier to use than some other methods, GaitMat did not achieve widespread appeal in clinical settings and gait laboratories. GaitMat II, an updated version, with a faster scanning rate, was better able to distinguish between left and right foot falls and had less complicated hardware. GaitMat II was recently used to study the effects of peripheral vascular disease on gait and may have more broad-based use in clinical and research facilities in the near future.[7]

Recently, the GAITRite system was introduced to measure temporal and spatial parameters of gait and to provide a functional outcome score patterned after Nelson's original paper-and-pencil method.[1] Its potential advantages are its portability, relatively low cost, and ease of operation and storage. Also, its on-board microprocessors connect to the serial port of conventional IBM-compatible computers, obviating the need for complicated and expensive circuit board adapters. Because of these potential advantages, the present study was undertaken to assess the GAITRite system's validity and reliability.

Table 3: Step Times at 3 Walking Rates: GAITRite Measures vs Video-Based Measures

Trial Description	Mean Step Time (s) Right VB	Right GR	Left VB	Left GR
1 Preferred	.55	.56	.63	.60
2 Slower than preferred	.69	.70	.76	.73
3 Faster than preferred	.45	.48	.57	.53

Traditionally, instrument validity has been established by comparing a system's performance against criterion standards whose validity has already been established. The GAITRite system measures both temporal and spatial parameters of gait, theoretically, at any speed. Our clinical experience with the device was encouraging; we believed that no single, previously developed and validated gait analysis method could provide both temporal and spatial data comparable with the GAITRite system's. Anticipating that the original paper-and-pencil method would yield more precise spatial measures, and that the video-based method would provide more accurate temporal measures, the first analysis compared the concurrent validity of the GAITRite system with the original paper-and-pencil (spatial measures) and video-based (temporal measures) methods as 2 criterion standards against which comparisons were made.

As was anticipated, ICCs were higher for spatial measure comparisons between GAITRite and the paper-and-pencil methods and were higher for temporal measure comparisons between the GAITRite and the video-based methods (see tables 1, 4). Two notably low correlations were found for cadence (ICC = .31) in the paper-and-pencil versus GAITRite comparison and right step length (ICC = .44) in the video-based versus GAITRite comparison. Cadence, as a derived calculation based on counted footfalls and elapsed walking time, is

Table 4: Correlations Among Paper-and-Pencil, Video-Based, and GAITRite Methods for 3 Analyses: Concurrent Gait Analysis, Step Length, and Step Time

	Concurrent Measures Validity (ICC 2, 1)			Step Length Reliability (Student's *t*, Paired)				Step Time Reliability (ICC 2, 1)	
				PP vs GR				VB vs GR	
Parameter	PP vs GR	VB vs GR		*t*	*df*	*p*		Left	Right
Walking speed	.96	.95	C Trials				ICC	.94	.99
Cadence	.31	.96	Step 1	.65	9	.53			
			Step 2	−.37	9	.72			
Right step length	.97	.44	Stride	1.19	9	.27			
Left step length	.99	.85	LOC Trials						
			Step 1	.89	9	.39			
Right step time	.67	.97	Step 2	−.32	9	.76			
Left step time	.61	.96	Stride	.92	9	.39			

sensitive to temporal measures and may have yielded an unacceptably low intraclass coefficient (ICC = .31) during the paper-and-pencil versus GAITRite analysis because of stopwatch timing errors (table 4). This consideration appears to be supported by correspondingly low correlations for right and left step times, which also rely on estimated timing. On the other hand, the video-based and GAITRite correlations were excellent for cadence (ICC = .96) and for right and left step times (ICC = .94 and .99, respectively).

We found excellent correlation (ICC > .95) for paper-and-pencil and GAITRite measures, for right and left step length, as anticipated, but only fair-to-good correlations in the video-based–GAITRite comparison (see table 4). The reason for a poor correlation (ICC = .44) for right step length remains unclear, but may have been caused by error from the video camera's depth-of-field as it recorded the right lower extremity. In the experimental setup, the video camera was always located to the subject's left side as she walked, leaving the right lower extremity always the farthest distance from the lens. The lens had a small aperture and the right lower extremity may have been located beyond the lens's depth-of-field, making the video image of the right limb blurred and causing difficulty in identifying the precise point of heel contact.

More accurate spatial data, (ie, step lengths) were found when we compared GAITRite results with the paper-and-pencil method. To assess whether the sensors embedded in the walkway were equally responsive to footfall pressures throughout the walkway's active recording area, we applied simulated steps and strides from a fabricated device (see fig 2) along the geographic centerline of the mat and along a line of progression left of center.

One difficulty noted in applying the simulated soles to the walkway was that footfall imprints were sometimes incomplete if care was not taken to press the device adequately into the walkway. During some trials, several imprints were incompletely registered by the sensors and appeared as partially formed footfalls on the software display. GAITRite's manufacturer recommends that the subject weigh at least 30 pounds to ensure that sufficient force is applied to the walkway to activate the embedded sensors. Although adults should be able to apply adequate force, small children may not be heavy enough. This issue should be investigated in future studies.

The present investigation used a single, healthy subject in 2 of the 3 experiments. The subject approximated abnormal gait patterns (eg, changes in symmetry and speed) as she walked along the GAITRite walkway. Because simulating a gait defect may not precisely replicate the gait pattern of individuals with injuries or disease, future analyses should include patients with gait disabilities. Our preliminary analyses of the GAITRite system appear to have direct clinical relevance for assessing gait performance with a relatively easy to use and inexpensive tool. Additional studies with patients will ultimately determine if the GAITRite system can offer broad-based appeal to clinicians and researchers. Future investigations should also assess the system's ability to measure other gait components accurately. Lower limb rotation and base of support, for instance, are important elements that may change when disease or physical injury produce permanent anatomic or biomechanic changes or changes in the control of gait.

CONCLUSIONS

Our preliminary analysis showed the GAITRite system to be a valid and reliable tool for measuring selected gait components: spatial parameters (step and stride lengths), temporal parameters (step lengths), and derived measures of rate in a healthy subject walking at difference speeds and various degrees of step symmetry. Future investigators should study patients with documented disease or physical injury. The GAITRite system proved to be an easy to use, relatively inexpensive gait assessment tool that clinicians and researchers may find useful for gait analysis in adults; some question remains about its usefulness for analyzing gait in very young or small children.

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