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Concurrent Validity and Test-retest Reliability of the OPTOGait Photoelectric Cell System for the Assessment of Spatio-temporal Parameters of the Gait of Young Adults

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Abstract. [Purpose] The purpose of this study was to investigate the concurrent validity and test-retest reliability of the recently introduced OPTOGait Photoelectric Cell System for the assessment of spatio-temporal parameters of gait. [Subjects] Twenty healthy young adults (mean age = 27.35, SD = 7.4) were asked to walk 3 times on walkway at a comfortable speed. [Methods] Concurrent validity was assessed by comparing data obtained using the OPTOGait and GAITRite systems, and reliability was assessed by comparing data from the first and third OPTOGait sessions. [Results] Concurrent validity, as identified by intra-class correlation coefficients (ICC (2, 1) = 0.929–0.998), coefficients of variation (CV_{ME} = 0.32–11.30%), and 95% limits of agreement, showed high levels of correlation. In addition, the test-retest reliability of the OPTOGait Photoelectric Cell System was demonstrated as showing a high level of correlation with all spatio-temporal parameters by intra-class correlation coefficients (ICC (3, 1) = 0.785–0.952), coefficients of variation (CV_{ME} = 1.66–4.06%), 95% limits of agreement, standard error of measurement (SEM = 2.17–5.96%), and minimum detectable change (MDC_{95}% = 6.01–16.52%). [Conclusion] The OPTOGait Photoelectric Cell System has strong concurrent validity along with relative and absolute test-retest reliabilities. This portable system with easy-to-use features can be used for clinical assessments or research purposes as an objective means of assessing gait.

Key words: Locomotion, Measurement, Analysis

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INTRODUCTION

Measurements of spatio-temporal parameters of gait are used to identify walking difficulties for diagnostics[1)], and to determine prognosis[2)]. The most common parameters selected for gait analysis are spatio-temporal parameters, which include walking speed, cadence, step length, stance time, swing time, and double support time[3)]. These parameters are commonly measured by video-based visual observation[4, 5)], using a stopwatch[6)], or using paper walkways[7, 8)]. However, these methods require considerable time, are labor-intensive, and are prone to inter-examiner and test-retest errors. Consequently, gait analysis system using computers are being increasingly used to obtain objective and accurate measurements of spatio-temporal gait parameters in clinical settings[9, 10)].

The GAITRite system is a portable walkway system that calculates spatio-temporal parameters using a pressure sensor mat. It is already in use in clinical settings as its results correspond well with those of other tests[11–13)] and it produces reliable results for subjects with various diseases[14–17)]. The OPTOJump® system (Microgate, Bolzano, Italy) is being used to measure functional parameters relevant to sporting activities such as vertical jumping. Since its validity and reliability are known, this system is widely used in clinical settings for assessment and research purposes[18–20)]. When the OPTOJump® system was upgraded to OPTOGait, it received attention as a possible means of analyzing gait and functional movement, as well as for measuring and recording spatio-temporal parameters. The OPTOGait system (OPTOGait, Microgate S.r.I, Italy, 2010) is composed of photoelectric cells sited along transmitting-receiving bars of 1 m in length that can be extended to 100 m with a maximum distance of 6 m between them. The transmitting-receiving bars contain infrared LED diodes, which enable communication between the two bars. When a subject passes between the transmitting bar and receiving bar, the system automatically calculates spatio-temporal parameters by sensing interruptions in communication.

The assessment results of a gait analysis system should be both valid and reliable. Concurrent validity can be established when concurrent measurements obtained from a de-

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vice are verified to meet certain standards[21]. Furthermore, the reliability of a gait analysis system is essential to determine whether a measure is actually due to a change in actual gait pattern rather than a systematic measurement error, in addition to determining differences in gaits between test sessions[14]. In a recent study, it was reported that the GAITRite and OPTOGait systems lack test-retest reliability of the elderly as well as total knee arthroplasty patients[22]. To use the OPTOGait system to assess spatio-temporal gait parameters of different subjects, assessment should be based on validity and reliability studies of healthy adults. Thus, the aims of this study were to provide useful information on the OPTOGait Photoelectric Cell System by measuring the spatio-temporal gait parameters of healthy adults walking at a comfortable speed, by examining the concurrent validity of the OPTOGait versus the GAITRite system, and by assessing its test-retest reliability.

SUBJECTS AND METHODS

Twenty young and healthy subjects (age = 27.35 ± 7.4 years), recruited from among the staff and students of a university, voluntarily participated in the experiment (9 females, 11 males; Height 170.9 ± 8.8 cm; Weight 62.3 ± 12.4 kg; BMI 21.13 ± 2.7 kg/m^2). Subjects were free from any cardiovascular, neurological, or musculoskeletal diseases, and had no walking difficulties. The study was conducted after obtaining approval from the ethics committee of Sahmyook University, and all participants provided their written informed consent.

Two researchers were responsible for system software and collecting data. General information, including height and weight, was recorded. To measure gait parameters, participants were asked to walk 3 times on a walkway at a comfortable speed. The participants started walking by using their right foot after being instructed to "Walk slowly at a comfortable speed" from 3 m in front of the walkway until 2 m beyond the end, after which they were instructed to turn around and walk back to the starting point. A 3-minute interval was given between individual assessments to transmit and save the data as well as to prepare for the next assessment. Participants took part in the experiment wearing socks but not shoes. Only steps in the sensor areas were included in the analysis.

Spatio-temporal gait parameters were measured by placing the OPTOGait unit on the GAITRite unit and operating both simultaneously. For the OPTOGait system (OPTOGait, Microgate S.r.I, Italy, 2010), the transmitting-receiving bars were 4 m long with a distance of 0.6 m between them. Ninety-six LED diodes are positioned on each bar 1 cm apart at 3 mm above the ground. When subjects pass between two bars positioned in parallel with the ground, transmission and reception are blocked by their feet. Timing, size, and distance are sensed, and spatio-temporal parameters are automatically calculated. Data were extracted at 1,000 Hz and saved on a PC using OPTOGait Version 1.6.4.0 software (Microgate S.r.I, Italy).

The GAITRite Electronic Walkway System (GaitRite, CIR System, Inc., NY, USA, 2011) used in this study was of standard size (length 460 × width 89 × height 0.625 cm) and contained 13,824 pressure sensors spaced at intervals of 1.27 cm, arranged in a grid formation. These pressure sensors are located on a mat, 3.6 m in length and 0.61 m in width. When subjects walk on the mat, sensors react to the contact. Using these reactions as an input, size, distance, and time is measured, and spatio-temporal gait parameters can be calculated. Data were extracted at 80 Hz, and the system was connected to a PC via a serial interface cable. Data saved on the computer were analyzed using GAITRite Gold Version 4.45 gait analysis software (CIR Systems NY, USA).

Data were analyzed using SPSS version 19.0. The spatio-temporal gait parameters measured were speed, cadence, step length, step time, stride length, single limb support time, double limb support time, and swing and stance times.

The results are presented as means and standard deviations of 3 measurements taken at a comfortable walking speed. The paired t-test was used to determine systematic differences between the gait parameters obtained using the two systems. Concurrent validities between OPTOGait and GAITRite were calculated using ICCs (2, 1)[21, 23]. Coefficients of variation of method errors (CV_{ME})[24] and 95% limits of agreement (LOA)[25] were calculated for the absolute comparison of parameters obtained using the two systems. As shown in the formula below, CV_{ME} values were converted into percentages by calculating coefficients of variation of method errors obtained using the standard deviations of differences between the results obtained using the two systems[24], and 95% LOA values were calculated as described by Bland and Altman[25].

$$ME = Sd / \sqrt{2}$$

$$CV_{ME} = 2ME / (X1+X2) \times 100\%$$

The test-retest reliabilities of gait parameters measured using the OPTOGait system were expressed as ICCs (3, 1) by comparing gait parameters obtained in the first and third sessions, as described by Shrout and Flessiss[23]. The paired t-test was used to identify systematic differences between the two sessions. For absolute comparison of the results obtained during the two sessions, CV_{ME}[24] and 95% LOA[25] were calculated and analyzed using scatter plots and Bland-Altman plots. In addition, standard errors of measurement (SEM) were calculated to measure the range of error of each gait parameter. SEM were calculated according to the formula $SD \times (1 - ICC2, 1)^{1/2}$ using the higher of the two SD measurements. For convenience of interpretation, SEM were expressed as the percentages of mean values (SEM%)[25]. In addition, to determine the smallest amount of change that is real and beyond the bound of measurement error, Minimum Detectable Changes (MDC_{95}) at a confidence level of 95% were calculated. This was performed by conversion to the percentage of the mean (MDC_{95}%) after calculating it using the formula $\sqrt{2} \times 1.96 \times SEM$[23, 26]. Statistical significance was accepted for p values < 0.05.

Table 1. Mean (SD) of spatiotemporal gait parameters of subjects and concurrent validity measured with GAITRite and OPTOGait

Gait Parameters	GAITRite	OPTOGait	ICC (2,1) 95%CI	95% LOA	CV(%)
Speed (m/s)	1.16 (0.18)	1.18 (0.17) ***	0.993 (0.988–0.996)	−0.062–0.022	1.37
Cadence (steps/min)	103.84 (10.17)	105.08 (10.10) ***	0.988 (0.980–0.993)	–4.43–1.86	1.00
Step length Lt. (cm)	67.56 (5.11)	67.77 (5.18) *	0.991 (0.984–0.994)	–1.587–1.168	0.56
Step length Rt. (cm)	66.65 (6.01)	67.07 (6.16) ***	0.996 (0.993–0.997)	–1.712–1.135	0.61
Step time Lt. (s)	0.58 (0.06)	0.58 (0.06)	0.997 (0.995–0.998)	–0.010–0.009	0.49
Step time Rt. (s)	0.58 (0.06)	0.58 (0.05)	0.995 (0.992–0.997)	–0.013–0.009	0.52
Stride length Lt. (cm)	134.05 (10.55)	134.40 (10.65) ***	0.998 (0.997–0.999)	–1.665–0.979	0.32
Stride length Rt. (cm)	134.59 (11.19)	134.94 (11.30) ***	0.998 (0.997–0.999)	–1.672–0.981	0.32
SLS Lt. (s)	0.43 (0.04)	0.41 (0.04) ***	0.973 (0.956–0.984)	0.005–0.041	3.98
SLS Rt. (s)	0.43 (0.04)	0.41 (0.04) ***	0.969 (0.948–0.981)	0.006–0.042	4.07
DLS (s)	0.27 (0.05)	0.31 (0.06) ***	0.963 (0.939–0.978)	–0.074–0.019	11.30
Stance phase Lt. (s)	0.72 (0.08)	0.75 (0.08) ***	0.929 (0.883–0.957)	–0.091–0.027	3.60
Stance phase Rt. (s)	0.72 (0.08)	0.75 (0.09) ***	0.953 (0.922–0.971)	–0.084–0.018	3.36
Swing phase Lt. (s)	0.43 (0.04)	0.41 (0.04) ***	0.969 (0.948–0.981)	0.006–0.042	4.07
Swing phase Rt. (s)	0.43 (0.04)	0.41 (0.04) ***	0.973 (0.956–0.984)	0.005–0.041	3.98

ICC, intra-class correlation coefficient; LOA, limits of agreement; $CV_{ME,}$ coefficients of variation of method error; SLS, Single Limb Support; DLS, Double Limb Support
Significant difference between the two measuring instruments (*, $p < 0.05$; ***, $p \leq 0.001$)

RESULTS

The mean and standard deviations of the spatio-temporal gait parameters are presented in Table 1. The paired t-test was used to determine systematic differences between the gait parameter values obtained by the two systems, and it was found that all spatio-temporal parameters were significantly different, except step time. Speed, cadence, step length, stride length, DLS time, and stance phase were greater in the OPTOGait system, whereas SLS time and swing phase were longer in the GAITRite system.

With regard to the spatio-temporal gait parameters, the concurrent validity between the two systems was excellent with ICC (2, 1) within the range of 0.929–0.998. CV_{ME} were relatively small for speed, cadence, step length, step time, and stride length (0.32−1.37%), whereas they were relatively large for SLS, DLS (3.98−11.30%), stance phase (3.37−3.60%), and swing phase (3.98−4.07%). At 95% LOA, SLS (Lt. 0.005–0.041; Rt. 0.006–0.042), DLS (−0.074 − −0.019), and swing phase (Lt. 0.006−0.042; Rt. 0.005−0.041) did not contain zero and were skewed to one side (Table 1).

Table 2 shows the means and standard deviations of gait parameters of the first and third sessions obtained by the OPTOGait system. The results of the paired t-test indicate that there was no significant difference between the two sessions.

Test-retest reliability of the gait parameters between these two sessions showed a high level of correlation with ICC (3, 1) within the range of 0.785–0.952. The CV_{ME} values of all parameters were relatively low, ranging from 1.66% to 4.06%. All parameters with 95% LOA containing zero were distributed in a symmetrical manner. For the two sessions, all parameters showed a low level of SEM between 2.17−5.96%, indicating strong and absolute reliability. MDC_{95}% values ranged from 6.01−16.52%, indicating a low level of variation between the two sessions (Table 2).

DISCUSSION

This study was conducted to investigate the concurrent validity between the OPTOGait and GAITRite systems with respect to the measurement of spatio-temporal gait parameters as well as to examine the test-retest reliability of OPTOGait of healthy young adults.

Systematic differences were found between the spatio-temporal parameter measurements made by the two systems. Single limb support time and swing phase time were both 4.65% higher as determined by the GAITRite system. However, by the OPTOGait system, double limb support time and stance phase time were 14.81% and 4.17% higher, respectively. As described by Lienhard et al.[22], the LED diodes of the OPTOGait system are positioned 3 mm higher than the pressure mat of GAITRite, and sensing of heel contact occurs sooner, and sensing of toe lift-off occurs later in the gait cycle. The observed systematic differences would have been caused by these timing differences.

Systematic differences were also found for speed, cadence, step length, and stride length. In contrast to the study by Lienhard et al.[22], measurements by OPTOGait were slightly greater than those by GAITRite. The reason for this can be explained as follows. A previous study compared one side of the lower leg of elderly people, who had a wide base due to obesity (average weight: 79.6 kg, height: 171 cm, and BMI: 26.97), with the affected limb of total knee arthroplasty patients. Most participants could not walk in a straight line and gait asymmetry was observed. In consequence, the GAITRite system, considering the line of progression, had a larger value than that of the OPTOGAIT system, which quantifies step length parallel to the bars re-

Table 2. Mean (SD) of the gait parameters and test-retest reliability of OPTOGait

Gait parameters	Session 1	Session 3	ICC (3, 1) 95%CI	95% LOA	CV (%)	SEM	SEM%	MDC_{95}	MDC_{95}%
Speed (m/s)	1.18 (0.19)	1.18 (0.18)	0.952 (0.883–0.981)	−0.018–0.116	2.74	0.04	3.53	0.12	9.78
Cadence (steps/min)	104.46 (10.10)	105.78 (9.35)	0.949 (0.876–0.979)	−4.780–7.420	1.68	2.28	2.17	6.32	6.01
Step length Lt. (cm)	67.70 (4.85)	67.75 (5.61)	0.785 (0.533–0.909)	−6.694–6.794	2.50	2.60	3.84	7.21	10.65
Step length Rt. (cm)	67.20 (7.02)	66.00 (6.70)	0.917 (0.802–0.966)	−6.692–4.292	2.24	2.02	3.04	5.61	8.42
Step time Lt. (s)	0.59 (0.07)	0.58 (0.06)	0.828 (0.616–0.928)	−0.079–0.073	2.72	0.03	4.96	0.08	13.76
Step time Rt. (s)	0.59 (0.05)	0.58 (0.05)	0.911 (0.790–0.964)	−0.051–0.035	2.23	0.01	2.74	0.04	7.07
Stride length Lt. (cm)	133.33 (11.81)	133.06 (13.33)	0.916 (0.800–0.966)	−10.394–9.860	1.78	3.86	2.90	10.71	8.04
Stride length Rt. (cm)	133.95 (13.19)	133.34 (13.43)	0.950 (0.877–0.980)	−12.339–4.242	1.66	3.00	2.25	8.32	6.23
SLS Lt. (s)	0.41 (0.04)	0.40 (0.04)	0.789 (0.541–0.911)	−0.056–0.039	3.28	0.02	4.54	0.05	12.58
SLS Rt. (s)	0.42 (0.04)	0.41 (0.03)	0.789 (0.541–0.911)	−0.056–0.036	2.59	0.02	4.43	0.05	12.27
DLS (s)	0.32 (0.06)	0.32 (0.05)	0.899 (0.764–0.959)	−0.047–0.052	4.06	0.02	5.96	0.05	16.52
Stance phase Lt. (s)	0.76 (0.09)	0.75 (0.08)	0.913 (0.794–0.965)	−0.082–0.052	2.19	0.03	3.52	0.07	9.75
Stance phase Rt. (s)	0.75 (0.09)	0.75 (0.09)	0.855 (0.669–0.940)	−0.096–0.093	2.96	0.03	4.57	0.09	12.67
Swing phase Lt. (s)	0.42 (0.04)	0.41 (0.03)	0.855 (0.669–0.940)	−0.056–0.036	2.59	0.02	3.67	0.04	10.17
Swing phase Rt. (s)	0.41 (0.04)	0.40 (0.04)	0.789 (0.541–0.911)	−0.056–0.039	3.28	0.02	4.54	0.05	12.58

ICC, intra-class correlation coefficient; LOA, limits of agreement; CV_{ME}, coefficients of variation of method error; SEM, standard error of measurement; MDC, minimum detectable change; SLS, Single Limb Support; DLS, Double Limb Support

gardless of the line of progression. However, considering that this study was conducted with normal healthy adults who tend to walk in a straight line, the slightly higher measurement obtained using the OPTOGait system is probably attributable to differences in the equipment, including sensor type and spacing.

Despite systematic differences between the two systems, a high level of correlation was found between the two systems with ICC within the range of 0.929–0.998, which is similar to the ICC of > 0.933 reported by Lienhard et al.[22] Menz et al.[14] suggested that although ICC is a more appropriate indicator of reliability than simple correlation coefficients (Pearson's r, Spearman's rho), a higher ICC does not necessarily mean high reliability. If the values of a sample are distributed over a wide range, a relatively high ICC can be achieved, even though score differences between the two measurements are widely distributed. Thus, it has been asserted that both coefficients of variation and limits of agreement[25] must be used simultaneously in order to reduce the effects of such intrinsic limitations, and to ensure absolute reliability. CV_{ME} expresses the differences between values obtained using the two systems as a percentage. By doing so, CV_{ME} can be used as a clinically useful indicator of consistency, since it is unaffected by sample heterogeneity[14]. 95% LOA represents the expected range of the difference between two measurements, and it is used to identify the presence of significant bias between two measurements when they are measured repeatedly.

The CV_{ME} for all spatio-temporal gait parameters obtained using the two systems were low, and 95% LOA values were distributed over a narrow range. However, the CV_{ME} for SLS (3.98%, 4.07%), DLS (11.30%), stance phase (3.60%, 3.36%), and swing phase (4.07%, 3.98%) were relatively higher than those for speed (1.37%), cadence (1.00%), step length (0.56%, 0.61%), step time (0.49%, 0.52%), and stride length (0.32%, 0.32%), indicating large differences between each measured parameter. Similarly, the 95% LOA values of SLS, DLS, and swing phase did not include zero or were skewed to one side compared to other values, indicating the presence of systematic bias. These results can be attributed to the different characteristics of the measurement methods used by the two systems, as mentioned earlier.

This study demonstrated high test-retest reliability and consistency with respect to the derivation of spatio-temporal gait parameters of healthy young adults using the OPTOGait system. For all parameters, ICC was > 0.789, indicating excellent test-retest reliability. Moreover, CV_{ME} values for all parameters were between 1.66–4.06%, and 95% LOA values including zero were within a narrow range with a symmetric distribution. These findings indicate slight changes between repeated measures using OPTOGAIT, and systematic bias was rarely observed.

Absolute reliability is as important as relative reliability. SEM is a quantitative expression of the range of error that can occur whenever the same participant repeats certain tests[21]. In this study, SEM calculated for test-retest were converted to percentages of mean values (SEM %) and showed a low level of measurement error, between 2.17–5.96%, indicating strong absolute reliability.

MDC is defined as the minimum change that can occur during measurement, not due to accidental change. Since it represents the degree of sensitivity to change, MDC is needed to assess whether or not actual change occurs during the performance of two sessions[27]. This value can be a straightforward criterion for assessing changes in a performed process. MDC values calculated in this study were relatively low (6.01–16.52%) when expressed as a percentage of means. This means that the measurements were sufficiently sensitive to change and indicate that all spatio-temporal parameters measured using the OPTOGait system can be usefully used to sense changes that occur in the gait process.

In this study, we demonstrated that the OPTOgait Photoelectric Cells System is a valid instrument for the assessment of spatiotemporal gait parameters of healthy young adults, and this is the first study of its kind to examine the test-retest reliability OPTOgait. The OPTOgait system has the benefit of being quick to setup, simple to use, and it is inexpensive, making it attractive to clinicians who need accurate gait data. However, when measuring gait parameters using the OPTOGait system, the gait characteristics of subjects should be considered. For example, it is difficult to use measurement equipment for a subject who drags his/her foot while walking, walks with step length shorter than his/her foot length, or uses an assistive device like a cane. Therefore, future investigations should study patients with documented diseases or physical injury. In addition, studies are needed to determine the suitability and validity of equipment, including electromyography (EMG) and treadmills. Clinicians could implement the assessment of spatio-temporal gait parameters using OPTOgait in a clinical setting or by monitoring patient progress during an intervention.

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