Absolute agreement and consistency of the OptoGait system and Freemed platform for measuring walking gait

Alejandro Núñez-Trull[1], Javier Alvarez-Medina[1], Diego Jaén-Carrillo[2*], Luis E. Roche-Seruendo[2], Eva Gómez-Trullén[1]

[1] Departamento de Fisiatría y Enfermería, Universidad de Zaragoza, Zaragoza, Spain

[2] Campus Universitario, Universidad San Jorge, Villanueva de Gállego, Zaragoza, Spain

[*] Corresponding author

Corresponding author:

Diego Jaén-Carrillo, PhD

Campus Universitario, Universidad San Joge. Aut. Mudéjar, km 299. 50830 Villanueva de Gállego, Zaragoza. Spain

Email: djaen@usj.es

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ABSTRACT

The gait cycle can be divided into four functional rocker units. Although the widespread use of the OptoGait (OG) system and the Freemed (FM) platform, their accuracy has not been tested. An observational study was completed with eighteen healthy volunteers to determine the accuracy of OG and FM for overground walking gait analysis. The pairwise comparison between data obtained from OG, FM and high-speed video analysis revealed significant differences for most of the measurements ($p < 0.05$). ICCs revealed an excellent absolute agreement between measurements (ICCs > 0.94) for all measures for OG systems compared to video-analysis. When considering FM vs. video-analysis, ICCs showed good absolute agreement for rocker 1 (ICC = 0.86) and 3 (ICC = 0.82), excellent for rocker 2 (ICC = 0.93) and poor (ICC < 0.5) for rocker 4. Bland-Altman plots (95% limits of agreement) revealed heteroscedasticity of error for OG in all variables for foot rockers ($r^2 > 0.1$) while no heteroscedasticity of error was found when using FM (r2< 0.1). This study indicates that the OG system and the FM platform can provide consistent foot rockers values when walking at a constant velocity. The differences between the systems assessed and their agreement and consistency values advise against their interchangeable use.

KEYWORDS

heel-off, pressure platform, rockers, testing

1. Introduction

Human gait occurs in a variety of patterns that are determined by elements such as the presence or absence of constant floor contact (i.e., walking or running, respectively) [1]. The normal walking gait is referred as a way of locomotion which involves the alternative use of the two legs, being at least one foot in contact with the ground, to offer support and propulsion [2].

Two different phases (i.e., stance and swing) constitute the normal gait cycle, which have been subdivided for analysis purposes. Whereas a single gait cycle begins when the foot first hits the ground (i.e., initial contact), a whole cycle of gait is completed when the same foot makes contact with the ground again [3]. The stance phase (which includes initial contact, loading response, and mid and terminal stance) is roughly 60% of the time is spent in the stance phase, while the swing phase is 40% (identifying initial, mid and terminal swing) [4]. During normal walking, both feet are in contact with the ground at two stages in the walking gait cycle: at the beginning and finish of the stance phase. These are known as 'double stance phase' and they make up around 10% of a gait cycle [3]. The gait cycle, particularly its stance phase, can also be thought of in terms of three functional rocker units, each with a distinct fulcrum, and the rockers are another way of thinking about the stance sub-phases [1].

The first rocker happens during the initial contact and loading response of the stance phase.

During this initial phase, the heel functions as a fulcrum around which the foot 'rotates' in terms of forward movement allowing the body to move forward [5]. The second rocker takes place at the mid-stance. The limb is moved over the foot, and the ankle, taken over as the fulcrum, is passively dorsiflexed [5]. During the terminal phase of the gait cycle, the third and fourth (toe-only) rockers occur. Here, the fulcrum has shifted to the metatarsal heads. The mid-tarsal joints lock, transforming the foot from a fluid structure to a stiff lever capable of propelling the body forward. The fourth (i.e., toe-only) rocker loads the weight-bearing portion of the foot closest to the metatarsal heads, providing a steady midstance and reducing toe shock on toe-off. [5].

Foot rockers analysis is not only key for gait acquisition, development, and retraining [6], but also it helps identify the severity of idiopathic toe walking [7]. Although the assessment of such events seems to be important for clinicians in revealing variations between pathological and non-pathological gait, it has received very little attention from the scientific community.

When analysing gait and related parameters, different technologies such as 3D motion capture systems, high-speed video analysis or wearable sensor are used [8, 9]. Commercially available systems for such analysis have limitations such as limited accessibility, high cost, sensory fragility, and operating complexity. Moreover, they are mostly used in research rather than therapeutic settings. It has been demonstrated that high-speed video analysis, as well as a 3-D motion capture device, is a reliable and valid method for measuring gait kinematics [10]. However, gait analysis and consequently foot rocker measurements employing the devices mentioned above is time consuming and needs highly trained users for a proper data collection and interpretation. This may result in a drawback for the everyday routine of clinicians. Here, less-time consuming and the user-friendly portable floor-level, high-density photoelectric cells (OptoGait, Microgate, Bolzano, Italy) and baropodometric platforms (Freemed, SensorMedica, Roma, Italy) are used in clinical settings to identify and quantify foot rockers of gait on most flat surfaces [11-14].

Previous research on the OptoGait™ system (OG) has considered its reliability when assessing kinematics walking and running gait variables [11, 15, 16]. Likewise, the Freemed™ baropodometric platform (FM) has been used for other purposes [12-14] and its validity has been proved for measuring spatiotemporal parameters and walking speed [17]. Despite the widespread use of both systems, their accuracy and consistency for measuring and identifying foot rockers during walking is still unknown, requiring further research. Thus, the aim of this study is to assess both the absolute agreement and consistency of both systems in comparison with high-speed video analysis for the measurement of foot rockers parameters while overground walking in healthy adults. It is hypothesised that both systems provide precise values when comparing with high-speed video analysis.

2. Methods

2.1. Experimental Approach to the problem

An observational study was carried out to determine absolute agreement and consistency of OG and FM compared with high-speed video-analysis when evaluating gait foot rockers following the STROBE guidelines [18]. The duration of the foot rockers (in ms) during walking was measured: (i) rocker 1 (R1); (ii) rocker 2 (R2); (iii) rocker 3 (R3); and (iv) rocker 4 (R4). This study was approved by the local bioethics committee (No. 009-19/20).

2.2. Participants

A total of eighteen men (age: 25±7 years; height: 1.72 ±0.06 m; weight: 70.3±9 kg), volunteered to participate in the present study meeting the inclusion criteria: i) older than 18 years, and ii) not suffering from any injury in the last 6 months before the data collection. Participants who presented any pathological gait were excluded. Before taking part in the study, all participants signed an informed consent in accordance with the ethical standards of the World Medical Association's Declaration of Helsinki (2013). The recruitment was done by convenience.

2.3. Procedures

This study was developed in a single session where participants completed an overground walking test at a comfortable speed. A researcher asked them to walk over a 10m walkway at a comfortable velocity [19]. Participants then started walking at a distance of 2m from the recording space and stopped 2m behind, reducing therefore both acceleration and deceleration effects. When participants reached that point, they turned around and walked back to the start [11]. They repeated this procedure for 3 minutes. Data from one step were collected for processing in the space between both photoelectric cells bar of the Optogait™, positioned one in front of the other, and on the Freemed™ baropodometric platform (Figure 1).

FIGURE 1 ABOUT HERE

The high-speed video camera was located parallel to the set-up (Optogait on Freemed) from a sagittal view, one meter away and at a height of 0.05 meters to record the same steps. This way, the very same steps were obtained from all the systems. During analysis, all the steps occurred in the sensor area.

2.4. Material and Testing

Height (cm) and weight (kg) were measured utilising a stadiometer (SECA 222; SECA Corp., Hamburg, Germany) and a weighing scale (Tanita BC-601; TANITA Corporation, Maeno-Cho, Itabashi-ku, Tokyo, Japan), respectively, for each participant.

The foot rockers parameters were measured first using the 1-meter bar of OptoGait Photoelectric Cell system (OptoGait, Microgate, Bolzano, Italy). The OptoGait system calibration was done by the manufacturer and consisted of two transmitting-receiving bars placed parallel to one another. The OptoGait system was connected to a computer through a USB cable, and the manufacturer's software was used (Version 1.12.1.0, Microgate, Bolzano, Italy). The filter parameters GAitR-In and GAitR-Out were both set at 1_1 to minimise the systematic bias [20, 21]. The data was recorded at 1,000 Hz sample frequency, encrypted, and saved on a computer. Thereafter, foot rockers were also measured using Freemed™ platform (Freemed, SensorMedica, Roma, Italy). The entire surface area of the platform is 635 x 700mm and it offers an active sensors area of 500 x 600 mm. The platform is capable of recording data at a sampling frequency of 350 Hz [22] and it was calibrated following manufacturer's recommendations and linked to a computer via USB. The manufacturer's software (Freestep v. 2.00.013, SensorMedica, Roma, Italy) was employed to analyse data.

For high-speed video analysis (VA), two-dimensional video data (at 1,000 Hz) were collected simultaneously using a high-speed camera (Imaging Source DFK 33UX174, The Imaging Source Europe GmbH; Germany) as previous studies have shown its validity [10, 23] and reliability [24] for measuring gait related parameters and thus served as a gold standard. The range of interest was adjusted to obtain 1,000 frames per second (784x144 resolution). One step per subject was recorded following the two-step method [25]. In order to control potential confounding factors (i.e., asymmetries) only the data of the right leg were considered [26].

For this particular study, each rocker was determined by identifying the initial and final frames and counting frames in-between for the following sequencies (Figure 2):

FIGURE 2 ABOUT HERE

(i) Rocker 1: From initial contact to flat foot (ms)

(ii) Rocker 2: Flat foot total time (ms)

(iii) Rocker 3: From heel-off to toe-off (ms)

(iv) Rocker 4: only-toe rocker (ms)

Of note, OG divides the foot rockers into three (R1, R2, and R3+R4), while the FM splits them into four as shown in Figure 2.

Data were analysed using the open license software Kinovea (version 0.8.27).

2.5. Statistical analysis

Mean standard deviation (±SD) is used to represent descriptive statistics. All data were subjected to normal distribution and homogeneity tests, as established by the Saphiro-Wilk and Levene's tests, prior to analysis. A pairwise mean comparison (t-test) was performed comparing data from the OptoGait and Freemed systems as well as the high-speed video analysis. To evaluate consistency of the values, a Pearson correlation analysis was done between each rocker measured by OptoGait (R1-R2-R3) and Freemed (R1-R2-R3-R4) and VA. The following criteria were used to interpret the level of correlation between measurements: <0.1 (trivial), 0.1-0.3 (small), 0.3-0.5 (moderate), 0.5-0.7 (large), 0.7-0.9 (very large), 0.9-1.0 (almost perfect) [27]. Furthermore, intra class correlation coefficients (ICC) for rockers during walking were evaluated between systems (i.e., OG vs VA and FM vs VA). Following the principles stated by Koo and Li [28] and based on the characteristics of this experimental design, the authors conducted a “two-way random-effects” model (ICC [2,1]), “single measurement” type, and “absolute agreement” definition for the ICC measurement. To analyse absolute agreement, the benchmarks reported in [28] were considered to interpret the ICC: ICC < 0.5 reflects ‘poor’, 0.5-0.75 ‘moderate’, 0.75-0.90 ‘good’, and > 0.90 ‘excellent’ reliability. The magnitude of the differences was interpreted using Cohen’s d effect size (*ES*) [29], being reported as: trivial (<0.2), small (0.2-0.49), medium (0.5-0.79), and large (≥0.8) [29]. To analyse differences in foot rockers features between measurements (i.e., OG, FM, VA) and between systems (i.e., OG vs. VA and FM vs. VA), the Bland-Altman [30] limits of agreement method (mean difference ± 1.96 SD) was used. Heteroscedasticity of error was defined as an r^2>0.1. All the statistical analyses have been done following Atkinson and Nevill recommendations for assessing reliability [31]. The level of significance used was p<0.05. Data analysis was performed using the SPSS (version 21, SPSS Inc., Chicago, Il.).

3. Results

Normal distribution and homogeneity, determined by the Shapiro-Wilk and Levene's test, respectively, were confirmed on all data before analysis (p > 0.05). The pairwise comparison between data obtained from OG, FM and VA revealed significant differences for most of the measurements (Table 1). Despite OG seems to significantly overestimate rocker 1 and rocker 3+4 when comparing to VA (p < 0.05), the effect size for rocker 1 was trivial (0.14) and for rocker 3+4 was large (0.81). When comparing FM vs. VA, it revealed significant differences for all the measurements (p < 0.05) and an effect size for rocker 1 considered trivial, medium for rocker 2, small for rocker 3, and large for rocker 4.

TABLE 1 ABOUT HERE

However, the consistency between measurements (Table 2) was almost perfect (r > 0.9) when comparing rocker 1 and 2 values obtained with OG and VA and when comparing values for rocker 2 and 3 using FM and VA. Moreover, very large (r > 0.7) agreements were found for rocker 3+4 when comparing OG vs. VA and for rocker 1 when FM vs. VA were considered. The ICCs also revealed a 'good' to 'excellent' association between measurements (ICCs > 0.84) for all the values for both systems compared to VA, excepting rocker 4 when considering FM vs. VA, which exhibited 'poor' agreement (ICC < 0.5).

TABLE 2 ABOUT HERE

Through Bland-Altman plots, figure 3 and figure 4 show the differences between the measurements obtained from OG and VA, and FM and VA, respectively, as well as the degree of agreement (95% limits of agreement) (Table 3). When using OG, heteroscedasticity of error was found in all variables for foot rockers ($r^2 > 0.1$) (Figure 3). However, no heteroscedasticity of error was found when using FM ($r^2 < 0.1$) (Figure 4).

TABLE 3 ABOUT HERE

FIGURE 3 ABOUT HERE

FIGURE 4 ABOUT HERE

4. Discussion

This study, to the best of the authors' knowledge, is the first study to evaluate the absolute agreement and consistency of both OptoGait system and Freemed platform for measuring foot rockers in overground walking. Here, 18 healthy participants were tested to pursue such aim. OptoGait showed the highest levels of absolute agreement for all the rockers (i.e., rocker 1, rocker 2, and rocker 3+4) exhibiting an excellent absolute agreement (ICC > 0.9 for all variables) when comparing to VA. However, although the levels of absolute agreement for rockers 1 and 3 showed good (ICC = 0.857 and 0.816, respectively) and rocker 2 exhibited an excellent absolute agreement (ICC = 0.930) when comparing FM to VA, poor absolute agreement was shown for rocker 4 (ICC = 0.253). Considering the information offered above, this section seeks to provide insights into the accuracy of both systems.

Absolute agreement and consistency are essential for a gait analysis system. These allow to distinguish whether discrepancies in gait parameters are either due to gait alterations or data collection errors. The results indicate that the values obtained from both OG and FM for foot rockers analysis were accurate, showing OG higher levels of agreement. The Bland-Altman analysis, on the other hand, sheds light on the systematic differences between the measurements. When OG was taken into account, all of the measured variables showed heteroscedasticity of error. On the other hand, none of the variables showed comparable heteroscedasticity when FM was considered except for rocker 2.

OG validity for assessing spatiotemporal variables for both treadmill walking [32] and running [20], and overground walking [33, 34] has been previously investigated. These studies dealt with the OG's validity to measure spatiotemporal parameters such as contact time, which is directly related to the stance phase in walking and, thus, to the different foot rockers here mentioned. Although gait analysis was assessed employing OG and comparing values against different reference systems (i.e., VA and instrumented treadmills), the analysis of foot rockers was omitted. Despite the fact that in the present study foot rockers were analysed during overground walking, our findings (ICC > 0.9) are endorsed by those found in a previous study [20] were the authors reported high ICCs (ICC = 0.981) when identifying contact time employing VA. The slightly differences between the values obtained in both studies may be attributed to the different protocols. While in our study participants were asked to walk overground, participants ran on a treadmill in the previous study [20]. When measuring foot rockers using FM and comparing to those measurements recorded with VA, good to excellent absolute agreement (ICC > 0.81) was found for rockers 1, 2 and 3.

The observed findings are consistent with results previously reported for spatiotemporal characteristics in healthy individuals [11, 35]. While Gomez-Bernal et al. evaluated the OG's reliability for spatiotemporal parameters analysis in treadmill walking [11] and Lee et al. asked their participants to walk three times at a comfortable speed on a sidewalk, the current study shows the of the OG system for foot rockers analysis in overground walking (rocker 1: r = 0.98, ICC = 0.98; rocker 2: r = 0.91 , ICC = 0.95; rocker 3+4: r = 0.88 , ICC = 0.94). Similarly, FM seems to provide 'good' to 'excellent' accurate measures for the analysis of foot rockers, except for rocker 4 (i.e., 'poor' = ICC < 0.5). Therefore, the accuracy of FM seems to be lower than the exhibited by the OG system. This might be explained given the differing frequencies the systems are able to use when recording data (OG = 1000 Hz and FM = 350 Hz). Based on the discrepancies between systems and their accuracy values, their interchangeable use when analysing gait parameters should be avoided.

Even though the current study gives some light on the usage of the OG and FM systems as accurate instruments for the evaluation of foot rockers, there are certain limitations to consider. First, although participants were asked to walk overground at their desired speed, the laboratory setting should be taken into account when analysing these results. Then, on one side, the 'almost perfect' reliability of the OptoGait system showed by the current results will provide future researchers enough evidence to use such system for the accuracy diagnosis of foot rockers in gait. On the other side, although the 'substantial' to 'almost perfect' reliability of the FM pressure found in this study might formulate some questions about its actual reliability, it establishes the first scientific evidence to keep developing research on such overspread-used pressure platform. This way of measuring rocker duration has not yet been used in the pathological population so there are no clinically meaningful measures to compare.

Future research should establish normative values of these gait phases with these systems in order to compare with pathological gait (neurological gait, idiopathic toe walking, clubfoot, and others). Because this study focused on young, healthy, male adults, future research should consider the evaluation of the systems with children, women, elderly and populations with pathological disorders.

5. Conclusion

The current study indicates that the OptoGait system and the Freemed platform can accurately assess foot rockers in young, healthy men walking at a constant speed. The findings presented here might be extremely useful for therapists working on both gait retraining and identification of pathologies. The user-friendliness of both the OptoGait system and the Freemed pressure platform, as well as their proven accuracy *vs.* high-speed video analysis for foot rockers analysis, gives clinicians a precise tool to make decisions about the degree of change due to the normal variability of measuring between trials or sessions, which is especially important for early detection of walking pathologies.

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References

[1] J. Perry, J.M. Burnfield, Gait analysis. Normal and pathological function 2nd ed, J California: Slack (2010).

[2] M.W. Whittle, Gait analysis: an introduction, Butterworth-Heinemann2014.

[3] M. Burnfield, Gait analysis: normal and pathological function, Journal of Sports Science and Medicine 9(2) (2010) 353.

[4] T. Stöckel, R. Jacksteit, M. Behrens, R. Skripitz, R. Bader, A. Mau-Moeller, The mental representation of the human gait in young and older adults, J Frontiers in psychology 6 (2015) 943.

[5] K. Shah, M. Solan, E.J.O. Dawe, Trauma, The gait cycle and its variations with disease and injury, 34(3) (2020) 153-160.

[6] D.E. Westberry, J.R. Davids, R.B. Davis, M.C. de Morais Filho, Idiopathic toe walking: a kinematic and kinetic profile, Journal of Pediatric Orthopaedics 28(3) (2008) 352-358.

[7] C. Alvarez, M. De Vera, R. Beauchamp, V. Ward, A. Black, Classification of idiopathic toe walking based on gait analysis: development and application of the ITW severity classification, Gait and posture 26(3) (2007) 428-435.

[8] F. Garcia-Pinillos, P.A. Latorre-Roman, V.M. Soto-Hermoso, J.A. Parraga-Montilla, A. Pantoja-Vallejo, R. Ramirez-Campillo, et al., Agreement between the spatiotemporal gait parameters from two different wearable devices and high-speed video analysis, PLoS One 14(9) (2019) e0222872. https://www.ncbi.nlm.nih.gov/pubmed/31550296.

[9] B. Mariani, H. Rouhani, X. Crevoisier, K.J.G. Aminian, posture, Quantitative estimation of foot-flat and stance phase of gait using foot-worn inertial sensors, 37(2) (2013) 229-234.

[10] C. Balsalobre-Fernandez, H. Agopyan, J.-B. Morin, The Validity and Reliability of an iPhone App for Measuring Running Mechanics, Journal of Applied Biomechanics 33(3) (2017) 222-226. <Go to ISI>://WOS:000405759500007.

[11] A. Gomez Bernal, R. Becerro-de-Bengoa-Vallejo, M.E. Losa-Iglesias, Reliability of the OptoGait portable photoelectric cell system for the quantification of spatial-temporal parameters of gait in young adults, Gait Posture 50 (2016) 196-200. http://www.ncbi.nlm.nih.gov/pubmed/27644096.

[12] B. Szczepanowska-Wołowiec, P. Sztandera, I. Kotela, M.J.I.J.o.E.R. Zak, P. Health, Assessment of the Foot's Longitudinal Arch by Different Indicators and Their Correlation with the Foot Loading Paradigm in School-Aged Children: A Cross Sectional Study, 18(10) (2021) 5196.

[13] B. Szczepanowska-Wolowiec, P. Sztandera, I. Kotela, M.J.B.m.d. Zak, Feet deformities and their close association with postural stability deficits in children aged 10–15 years, 20(1) (2019) 1-9.

[14] W. Forczek, A. Masłoń, B. Frączek, M. Curyło, M. Salamaga, A.J.P.o. Suder, Does the first trimester of pregnancy induce alterations in the walking pattern?, 14(1) (2019) e0209766.

[15] M.M. Lee, C.H. Song, K.J. Lee, S.W. Jung, D.C. Shin, S.H. Shin, 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, Journal of physical therapy science 26(1) (2014) 81-85.

[16] D. Jaén-Carrillo, F. García-Pinillos, A. Cartón-Llorente, A.J. Almenar-Arasanz, J.A. Bustillo-Pelayo, L.E. Roche-Seruendo, Test–retest reliability of the OptoGait system for the analysis of spatiotemporal running gait parameters and lower body stiffness in healthy adults, Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology (2020) 1754337119898353.

[17] L. Correale, V.C. Pellino, L. Marin, M. Febbi, M. Vandoni, Comparison of an inertial measurement unit system and baropodometric platform for measuring spatiotemporal parameters and walking speed in healthy adults, Motor Control 25(1) (2020) 89-99.

[18] E. Von Elm, D.G. Altman, M. Egger, S.J. Pocock, P.C. Gøtzsche, J.P. Vandenbroucke, The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies, Annals of internal medicine 147(8) (2007) 573-577.

[19] K.E. Webster, J.E. Wittwer, J.A. Feller, Validity of the GAITRite® walkway system for the measurement of averaged and individual step parameters of gait, Gait & posture 22(4) (2005) 317-321.
[20] F. García-Pinillos, P.Á. Latorre-Román, R. Ramirez-Campillo, L.E. Roche-Seruendo, Agreement between spatiotemporal parameters from a photoelectric system with different filter settings and high-speed video analysis during running on a treadmill at comfortable velocity, Journal of biomechanics (2019).
[21] B. Hanley, C.B. Tucker, Reliability of the OptoJump Next System for Measuring Temporal Values in Elite Racewalking, Journal of strength and conditioning research (2019).
[22] SensorMedica, https://www.sensormedica.com/site/en/products/platforms-freemed z dn, (accessed 03/08/2022 2022).
[23] J.-F. Esculier, T. Silvini, L.J. Bouyer, J.-S. Roy, Video-based assessment of foot strike pattern and step rate is valid and reliable in runners with patellofemoral pain, Physical Therapy in Sport 29 (2018) 108-112.
[24] A. Pipkin, K. Kotecki, S. Hetzel, B. Heiderscheit, Reliability of a Qualitative Video Analysis for Running, J Orthop Sports Phys Ther 46(7) (2016) 556-61. http://www.ncbi.nlm.nih.gov/pubmed/27266886.
[25] T.G. McPoil, M.W. Cornwall, L. Dupuis, M. Cornwell, Variability of plantar pressure data. A comparison of the two-step and midgait methods, Journal of the American Podiatric Medical Association 89(10) (1999) 495-501.
[26] K.N. Radzak, A.M. Putnam, K. Tamura, R.K. Hetzler, C.D. Stickley, Asymmetry between lower limbs during rested and fatigued state running gait in healthy individuals, Gait Posture 51 (2017) 268-274. http://www.ncbi.nlm.nih.gov/pubmed/27842295.
[27] W. Hopkins, S. Marshall, A. Batterham, J. Hanin, Progressive statistics for studies in sports medicine and exercise science, Medicine Science in Sports Exercise 41(1) (2009) 3.
[28] T.K. Koo, M.Y. Li, A guideline of selecting and reporting intraclass correlation coefficients for reliability research, Journal of chiropractic medicine 15(2) (2016) 155-163.
[29] J. Cohen, Statistical power analysis, Current directions in psychological science 1(3) (1992) 98-101.
[30] J.M. Bland, D.G. Altman, Comparing methods of measurement: why plotting difference against standard method is misleading, The lancet 346(8982) (1995) 1085-1087.
[31] G. Atkinson, A.M. Nevill, Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine, Sports medicine 26(4) (1998) 217-238.
[32] M. Lee, C. Song, K. Lee, D. Shin, S.J.M.s.m.i.m.j.o.e. Shin, c. research, Agreement between the spatio-temporal gait parameters from treadmill-based photoelectric cell and the instrumented treadmill system in healthy young adults and stroke patients, 20 (2014) 1210.
[33] A. Healy, K. Linyard-Tough, N. Chockalingam, Agreement Between the Spatiotemporal Gait Parameters of Healthy Adults From the OptoGait System and a Traditional Three-Dimensional Motion Capture System, J Biomech Eng 141(1) (2019). http://www.ncbi.nlm.nih.gov/pubmed/30285079.
[34] K. Lienhard, D. Schneider, N.A. Maffiuletti, Validity of the Optogait photoelectric system for the assessment of spatiotemporal gait parameters, Med Eng Phys 35(4) (2013) 500-4. http://www.ncbi.nlm.nih.gov/pubmed/22818403.
[35] M.M. Lee, C.H. Song, K.J. Lee, S.W. Jung, D.C. Shin, S.H. Shin, 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, Journal of physical therapy science 26(1) (2014) 81-5. http://www.ncbi.nlm.nih.gov/pubmed/24567681.

TABLES

Table 1. *Mean measurements and effect size of foot rockers in gait measured with OptoGait and Freemed and compared against values obtained with high-speed video analysis.*

Variable	OG (±SD)	FM (±SD)	VA (±SD)	OG vs VA Δ (%)	OG vs VA p-value^ (ES)	FM vs VA Δ (%)	FM vs VA p-value^ (ES)
Rocker 1 (ms)	116.66 (45.25)	155.22 (56.61)	123.39 (49.6)	-6.72 (13)	0.026* (0.14)	31.83 (17)	0.000* (0.07)
Rocker 2 (ms)	448.44 (104.49)	399.28 (101.305)	426.00 (122.28)	22.44 (50)	0.056 (0.26)	-26.72 (47)	0.047* (0.69)
Rocker 3+4 (ms)	329.75 (75.81)		348.72 (64.23)	-18.97 (37)	0.014* (0.81)		
Rocker 3 (ms)		323.33 (57.54)	275.44 (55.59)			47.89 (35)	0.000* (0.34)
Rocker 4 (ms)		36.50 (19.28)	73.28 (18.44)			-36.78 (1)	0.000* (2.46)

OG: OptoGait; FM: Freemed; VA: high-speed video analysis; SD: Standard deviation; Δ: Difference between measurements obtained from both systems; ES: Cohen's d effect size

^ calculated by pairwise mean comparison (t-test)

* $p < 0.05$

Table 2. *Pearson coefficients and intraclass correlation coefficients (ICC [2,1]) for comparisons between foot rockers obtained from OptoGait and Freemed against high-speed video analysis.*

Variable		OG_R1	OG_R2	OG_R3+4	FM_R1	FM_R2	FM_R3	FM_R4
VA_R1	Pearson coefficient (r)	0.980*			0.793*			
	Sig.	0.000			0.000			
	ICC (95% CI)	0.980 (0.934 – 0.993)			0.857 (0.028 – 0.962)			
VA_R2	Pearson coefficient (r)		0.907*			0.915*		
	Sig.		0.000			0.000		
	ICC (95% CI)		0.949 (0.852 – 0.982)			0.930 (0.795 – 0.975)		
VA_R3+4	Pearson coefficient (r)			0.884*				
	Sig.			0.000				
	ICC (95% CI)			0.939 (0.777 – 0.979)				
VA_R3	Pearson coefficient (r)						0.912*	
	Sig.						0.000	
	ICC (95% CI)						0.816 (-0.136 – 0.959)	
VA_R4	Pearson coefficient (r)							0.382
	Sig.							0.117
	ICC (95% CI)							0.253 (-0.191 – 0.645)

VA_R1: first rocker measured with high-speed video analysis; VA_R2: second rocker measured with high-speed video analysis;VA_R3+4: third and fourth rockers measured with high-speed video analysis; VA_R3: third rocker measured with high-speed video analysis; VA_R4: fourth rocker measured with high-speed video analysis;OG_R1: first rocker measured with OptoGait; OG_R2:second rocker measured with OptoGait;OG_R3+4:third and fourth rockers measured with OptoGait; FM_R1: first rocker measured with Freemed; FM_R2: second rocker measured with Freemed; FM_R3: third rocker measured with Freemed; FM_R4: fourth rocker measured with Freemed; ICC: intraclass correlation coefficient; CI: Confidence interval

* $p < 0.05$

Table 3. *Bland & Altman Bias and 95% Limits of Agreement.*

Parameter	OG vs VA			FM vs VA		
	Bias (SD)	Lower LOA	Upper LOA	Bias (±SD)	Lower LOA	Upper LOA
Rocker 1 (ms)	6.72 (±11.69)	68.3722	255.3722	-31.83 (±26.19)	97.8798	312.3798
Rocker 2 (ms)	-22.44 (±46.51)	357.0104	797.0104	26.72 (±52.88)	330.7540	778.2540
Rocker 3+4 (ms)	18.97 (±29.42)	284.3362	563.5862	-	-	-
Rocker 3 (ms)	-	-	-	-47.89 (±20.66)	256.3245	445.8245
Rocker 4 (ms)	-	-	-	36.78 (±20.39)	67.7896	126.7896

OG: OptoGait; FM: Freemed; VA: high-speed video analysis; SD: Standard deviation; LOA: 95 Limit of agreement

FIGURE CAPTIONS

Figure 1. Picture of OptoGait system on Freemed baropodometric platform for data collection.

Figure 2. Foot rockers diagram for analysis.

Figure 3. OG vs. VA differences between the measurements (systematic bias and random error) and the degree of agreement (95% limits of agreement) for rockers 1 (3.A), 2 (3.B) and 3+4 (3.C). The plot includes the mean difference (dotted line) and 95% limits of agreement (dashed line), along with the regression line (solid line).

Figure 4. FM vs. VA differences between the measurements (systematic bias and random error) and the degree of agreement (95% limits of agreement) for rockers 1 (4.A), 2 (4.B), 3 (4.C) and 4 (4.D). The plot includes the mean difference (dotted line) and 95% limits of agreement (dashed line), along with the regression line (solid line).

Absolute agreement and consistency of the OptoGait system and Freemed platform for measuring walking gait

Alejandro Núñez-Trull[1], Javier Alvarez-Medina[1], Diego Jaén-Carrillo[2*], Luis E. Roche-Seruendo[2], Eva Gómez-Trullén[1]

[1] Departamento de Fisiatría y Enfermería, Universidad de Zaragoza, Zaragoza, Spain

[2] Campus Universitario, Universidad San Jorge, Villanueva de Gállego, Zaragoza, Spain

[*] Corresponding author

Corresponding author:

Diego Jaén-Carrillo, PhD

Campus Universitario, Universidad San Joge. Aut. Mudéjar, km 299. 50830 Villanueva de Gállego, Zaragoza. Spain

Email: djaen@usj.es

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ABSTRACT

The gait cycle can be divided into ~~three~~ four functional rocker units. Although the widespread use of the OptoGait (OG) system and the Freemed (FM) platform, their accuracy has not been tested. An observational study was completed with eighteen healthy volunteers to determine the accuracy of OG and FM for overground walking gait analysis. The pairwise comparison between data obtained from OG, FM and high-speed video analysis revealed significant differences for most of the measurements ($p < 0.05$). ICCs revealed an excellent absolute agreement between measurements (ICCs > 0.94) for all measures for OG systems compared to video-analysis. When considering FM vs. video-analysis, ICCs showed good absolute agreement for rocker 1 (ICC = 0.86) and 3 (ICC = 0.82), excellent for rocker 2 (ICC = 0.93) and poor (ICC < 0.5) for rocker 4. Bland-Altman plots (95% limits of agreement) revealed heteroscedasticity of error for OG in all variables for foot rockers ($r^2 > 0.1$) while no heteroscedasticity of error was found when using ~~SM~~ FM (r2< 0.1). This study indicates that the OG system and the FM platform can provide ~~adequate~~ consistent foot rockers values when walking at a constant velocity. The differences between the systems assessed and their ~~accuracy~~ agreement and consistency values advise against their interchangeable use.

KEYWORDS

heel-off, pressure platform, rockers, testing

1. Introduction

Human gait occurs in a variety of patterns that are determined by elements such as the presence or absence of constant floor contact (i.e., walking or running, respectively) [1]. The normal walking gait is referred as a way of locomotion which involves the alternative use of the two legs, being at least one foot in contact with the ground, to offer support and propulsion [2].

Two different phases (i.e., stance and swing) constitute the normal gait cycle, which have been subdivided for analysis purposes. Whereas a single gait cycle begins when the foot first hits the ground (i.e., initial contact), a whole cycle of gait is completed when the same foot makes contact with the ground again [3]. The stance phase (which includes initial contact, loading response, and mid and terminal stance) is roughly 60% of the time is spent in the stance phase, while the swing phase is 40% (identifying initial, mid and terminal swing) [4]. During normal walking, both feet are in contact with the ground at two stages in the walking gait cycle: at the beginning and finish of the stance phase. These are known as 'double stance phase' and they make up around 10% of a gait cycle [3]. The gait cycle, particularly its stance phase, can also be thought of in terms of three functional rocker units, each with a distinct fulcrum, and the rockers are another way of thinking about the stance sub-phases [1].

The first rocker happens during the initial contact and loading response of the stance phase.

During this initial phase, the heel functions as a fulcrum around which the foot 'rotates' in terms of forward movement allowing the body to move forward [5]. The second rocker takes place at the mid-stance. The limb is moved over the foot, and the ankle, taken over as the fulcrum, is passively dorsiflexed [5]. During the terminal phase of the gait cycle, the third and fourth (toe-only) rockers occur. Here, the fulcrum has shifted to the metatarsal heads. The mid-tarsal joints lock, transforming the foot from a fluid structure to a stiff lever capable of propelling the body forward. The fourth (i.e., toe-only) rocker loads the weight-bearing portion of the foot closest to the metatarsal heads, providing a steady midstance and reducing toe shock on toe-off. [5].

Foot rockers analysis is not only key for gait acquisition, development, and retraining [6], but also it helps identify the severity of idiopathic toe walking [7]. Although the assessment of such events seems to be important for clinicians in revealing variations between pathological and non-pathological gait, it has received very little attention from the scientific community.

When analysing gait and related parameters, different technologies such as 3D motion capture systems, high-speed video analysis or wearable sensor are used [8, 9]. Commercially available systems for such analysis have limitations such as limited accessibility, high cost, sensory fragility, and operating complexity. Moreover, they are mostly used in research rather than therapeutic settings. It has been demonstrated that high-speed video analysis, as well as a 3-D motion capture device, is a reliable and valid method for measuring gait kinematics [10]. However, gait analysis and consequently foot rocker measurements employing the devices mentioned above is time consuming and needs highly trained users for a proper data collection and interpretation. This may result in a drawback for the everyday routine of clinicians. Here, less-time consuming and the user-friendly portable floor-level, high-density photoelectric cells (OptoGait, Microgate, Bolzano, Italy) and baropodometric platforms (Freemed, SensorMedica, Roma, Italy) are used in clinical settings to identify and quantify foot rockers of gait on most flat surfaces [11-14].

Previous research on the OptoGait™ system (OG) has considered its reliability when assessing kinematics walking and running gait variables [11, 15, 16]. Likewise, the Freemed™ baropodometric platform (FM) has been used for other purposes [12-14] and its validity has been proved for measuring spatiotemporal parameters and walking speed [17]. Despite the widespread use of both systems, their accuracy and consistency for measuring and identifying foot rockers during walking is still unknown, requiring further research. Thus, the aim of this study is to assess both the absolute agreement and consistency of both systems in comparison with high-speed video analysis for the measurement of foot rockers parameters while overground walking in healthy adults. It is hypothesised that both systems provide precise values when comparing with high-speed video analysis.

2. Methods

2.1. Experimental Approach to the problem

An observational study was carried out to determine absolute agreement and consistency of OG and FM compared with high-speed video-analysis when evaluating gait foot rockers following the STROBE guidelines [18]. The duration of the foot rockers (in ms) during walking was measured: (i) rocker 1 (R1); (ii) rocker 2 (R2); (iii) rocker 3 (R3); and (iv) rocker 4 (R4). This study was approved by the local bioethics committee (No. 009-19/20).

2.2. Participants

A total of eighteen men (age: 25±7 years; height: 1.72 ±0.06 m; weight: 70.3±9 kg), volunteered to participate in the present study meeting the inclusion criteria: i) older than 18 years, and ii) not suffering from any injury in the last 6 months before the data collection. Participants who presented any pathological gait were excluded. Before taking part in the study, all participants signed an informed consent in accordance with the ethical standards of the World Medical Association's Declaration of Helsinki (2013). The recruitment was done by convenience.

2.3. Procedures

This study was developed in a single session where participants completed an overground walking test at a comfortable speed. A researcher asked them to walk over a 10m walkway at a comfortable velocity [19]. Participants then started walking at a distance of 2m from the recording space and stopped 2m behind, reducing therefore both acceleration and deceleration effects. When participants reached that point, they turned around and walked back to the start [11]. They repeated this procedure for 3 minutes. Data from one step were collected for processing in the space between both photoelectric cells bar of the Optogait™, positioned one in front of the other, and on the Freemed™ baropodometric platform (Figure 1).

FIGURE 1 ABOUT HERE

The high-speed video camera was located parallel to the set-up (Optogait on Freemed) from a sagittal view, one meter away and at a height of 0.05 meters to record the same steps. This way, the very same steps were obtained from all the systems. During analysis, all the steps occurred in the sensor area.

2.4. Material and Testing

Height (cm) and weight (kg) were measured utilising a stadiometer (SECA 222; SECA Corp., Hamburg, Germany) and a weighing scale (Tanita BC-601; TANITA Corporation, Maeno-Cho, Itabashi-ku, Tokyo, Japan), respectively, for each participant.

The foot rockers parameters were measured first using the 1-meter bar of OptoGait Photoelectric Cell system (OptoGait, Microgate, Bolzano, Italy). The OptoGait system calibration was done by the manufacturer and consisted of two transmitting-receiving bars placed parallel to one another. The OptoGait system was connected to a computer through a USB cable, and the manufacturer's software was used (Version 1.12.1.0, Microgate, Bolzano, Italy). The filter parameters GAitR-In and GAitR-Out were both set at 1_1 to minimise the systematic bias [20, 21]. The data was recorded at 1,000 Hz sample frequency, encrypted, and saved on a computer. Thereafter, foot rockers were also measured using Freemed™ platform (Freemed, SensorMedica, Roma, Italy). The entire surface area of the platform is 635 x 700mm and it offers an active sensors area of 500 x 600 mm. The platform is capable of recording data at a sampling frequency of 350 Hz [22] and it was calibrated following manufacturer's recommendations and linked to a computer via USB. The manufacturer's software (Freestep v. 2.00.013, SensorMedica, Roma, Italy) was employed to analyse data.

For high-speed video analysis (VA), two-dimensional video data (at 1,000 Hz) were collected simultaneously using a high-speed camera (Imaging Source DFK 33UX174, The Imaging Source Europe GmbH; Germany) as previous studies have shown its validity [10, 23] and reliability [24] for measuring gait related parameters and thus served as a gold standard. The range of interest was adjusted to obtain 1,000 frames per second (784x144 resolution). One step per subject was recorded following the two-step method [25]. In order to control potential confounding factors (i.e., asymmetries) only the data of the right leg were considered [26].

For this particular study, each rocker was determined by identifying the initial and final frames and counting frames in-between for the following sequencies (Figure 2):

FIGURE 2 ABOUT HERE

(i) Rocker 1: From initial contact to flat foot (ms)

(ii) Rocker 2: Flat foot total time (ms)

(iii) Rocker 3: From heel-off to toe-off (ms)

(iv) Rocker 4: only-toe rocker (ms)

Of note, OG divides the foot rockers into three (R1, R2, and R3+R4), while the FM splits them into four as shown in Figure 2.

Data were analysed using the open license software Kinovea (version 0.8.27).

2.5. Statistical analysis

Mean standard deviation (±SD) is used to represent descriptive statistics. All data were subjected to normal distribution and homogeneity tests, as established by the Saphiro-Wilk and Levene's tests, prior to analysis. A pairwise mean comparison (t-test) was performed comparing data from the OptoGait and Freemed systems as well as the high-speed video analysis. To evaluate consistency of the values, a Pearson correlation analysis was done between each rocker measured by OptoGait (R1-R2-R3) and Freemed (R1-R2-R3-R4) and VA. The following criteria were used to interpret the level of correlation between measurements: <0.1 (trivial), 0.1-0.3 (small), 0.3-0.5 (moderate), 0.5-0.7 (large), 0.7-0.9 (very large), 0.9-1.0 (almost perfect) [27]. Furthermore, intra class correlation coefficients (ICC) for rockers during walking were evaluated between systems (i.e., OG vs VA and FM vs VA). Following the principles stated by Koo and Li [28] and based on the characteristics of this experimental design, the authors conducted a “two-way random-effects” model (ICC [2,1]), “single measurement” type, and “absolute agreement” definition for the ICC measurement. To analyse absolute agreement, the benchmarks reported in [28] were considered to interpret the ICC: ICC < 0.5 reflects ‘poor’, 0.5-0.75 ‘moderate’, 0.75-0.90 ‘good’, and > 0.90 ‘excellent’ reliability. The magnitude of the differences was interpreted using Cohen’s d effect size (*ES*) [29], being reported as: trivial (<0.2), small (0.2-0.49), medium (0.5-0.79), and large (≥0.8) [29]. To analyse differences in foot rockers features between measurements (i.e., OG, FM, VA) and between systems (i.e., OG vs. VA and FM vs. VA), the Bland-Altman [30] limits of agreement method (mean difference ± 1.96 SD) was used. Heteroscedasticity of error was defined as an $r^2>0.1$. All the statistical analyses have been done following Atkinson and Nevill recommendations for assessing reliability [31]. The level of significance used was $p<0.05$. Data analysis was performed using the SPSS (version 21, SPSS Inc., Chicago, Il.).

3. Results

Normal distribution and homogeneity, determined by the Shapiro-Wilk and Levene's test, respectively, were confirmed on all data before analysis ($p > 0.05$). The pairwise comparison between data obtained from OG, ~~SM~~ FM and VA revealed significant differences for most of the measurements (Table 1). Despite OG seems to significantly overestimate rocker 1 and rocker 3+4 when comparing to VA ($p < 0.05$), the effect size for rocker 1 was trivial (0.14) and for rocker 3+4 was large (0.81). When comparing FM vs. VA, it revealed significant differences for all the measurements ($p < 0.05$) and an effect size for rocker 1 considered trivial, medium for rocker 2, small for rocker 3, and large for rocker 4.

TABLE 1 ABOUT HERE

However, the consistency between measurements (Table 2) was almost perfect ($r > 0.9$) when comparing rocker 1 and 2 values obtained with OG and VA and when comparing values for rocker 2 and 3 using FM and VA. Moreover, very large ($r > 0.7$) agreements were found for rocker 3+4 when comparing OG vs. VA and for rocker 1 when FM vs. VA were considered. The ICCs also revealed a 'good' to 'excellent' association between measurements (ICCs > 0.84) for all the values for both systems compared to VA, excepting rocker 4 when considering FM vs. VA, which exhibited 'poor' agreement (ICC < 0.5).

TABLE 2 ABOUT HERE

Through Bland-Altman plots, figure 3 and figure 4 show the differences between the measurements obtained from OG and VA, and FM and VA, respectively, as well as the degree of agreement (95% limits of agreement) (Table 3). When using OG, heteroscedasticity of error was found in all variables for foot rockers (r^2> 0.1) (Figure 3). However, no heteroscedasticity of error was found when using ~~SM~~ FM (r^2< 0.1) (Figure 4).

TABLE 3 ABOUT HERE

FIGURE 3 ABOUT HERE

FIGURE 4 ABOUT HERE

4. Discussion

This study, to the best of the authors' knowledge, is the first study to evaluate the absolute agreement and consistency of both OptoGait system and Freemed platform for measuring foot rockers in overground walking. Here, 18 healthy participants were tested to pursue such aim. OptoGait showed the highest levels of absolute agreement for all the rockers (i.e., rocker 1, rocker 2, and rocker 3+4) exhibiting an excellent absolute agreement (ICC > 0.9 for all variables) when comparing to VA. However, although the levels of absolute agreement for rockers 1 and 3 showed good (ICC = 0.857 and 0.816, respectively) and rocker 2 exhibited an excellent absolute agreement (ICC = 0.930) when comparing ~~SM~~ FM to VA, poor absolute agreement was shown for rocker 4 (ICC = 0.253). Considering the information offered above, this section seeks to provide insights into the accuracy of both systems.

Absolute agreement and consistency are essential for a gait analysis system. These allow to distinguish whether discrepancies in gait parameters are either due to gait alterations or data collection errors. The results indicate that the values obtained from both OG and FM for foot rockers analysis were accurate, showing OG higher levels of agreement. The Bland-Altman analysis, on the other hand, sheds light on the systematic differences between the measurements. When OG was taken into account, all of the measured variables showed heteroscedasticity of error. On the other hand, none of the variables showed comparable heteroscedasticity when FM was considered except for rocker 2.

OG validity for assessing spatiotemporal variables for both treadmill walking [32] and running [20], and overground walking [33, 34] has been previously investigated. These studies dealt with the OG's validity to measure spatiotemporal parameters such as contact time, which is directly related to the stance phase in walking and, thus, to the different foot rockers here mentioned. Although gait analysis was assessed employing OG and comparing values against different reference systems (i.e., VA and instrumented treadmills), the analysis of foot rockers was omitted. Despite the fact that in the present study foot rockers were analysed during overground walking, our findings (ICC > 0.9) are endorsed by those found in a previous study [20] were the authors reported high ICCs (ICC = 0.981) when identifying contact time employing VA. The slightly differences between the values obtained in both studies may be attributed to the different protocols. While in our study participants were asked to walk overground, participants ran on a treadmill in the previous study [20]. When measuring foot rockers using FM and comparing to those measurements recorded with VA, good to excellent absolute agreement (ICC > 0.81) was found for rockers 1, 2 and 3.

The observed findings are consistent with results previously reported for spatiotemporal characteristics in healthy individuals [11, 35]. While Gomez-Bernal et al. evaluated the OG's reliability for spatiotemporal parameters analysis in treadmill walking [11] and Lee et al. asked their participants to walk three times at a comfortable speed on a sidewalk, the current study shows the of the OG system for foot rockers analysis in overground walking (rocker 1: r = 0.98, ICC = 0.98; rocker 2: r = 0.91 , ICC = 0.95; rocker 3+4: r = 0.88 , ICC = 0.94). Similarly, FM seems to provide 'good' to 'excellent' accurate measures for the analysis of foot rockers, except for rocker 4 (i.e., 'poor' = ICC < 0.5). Therefore, the accuracy of FM seems to be lower than the exhibited by the OG system. This might be explained given the differing frequencies the systems are able to use when recording data (OG = 1000 Hz and ~~SM~~ FM = 350 Hz). Based on the discrepancies between systems and their accuracy values, their interchangeable use when analysing gait parameters should be avoided.

Even though the current study gives some light on the usage of the OG and FM systems as accurate instruments for the evaluation of foot rockers, there are certain limitations to consider. First, although participants were asked to walk overground at their desired speed, the laboratory setting should be taken into account when analysing these results. Then, on one side, the 'almost perfect' reliability of the OptoGait system showed by the current results will provide future researchers enough evidence to use such system for the accuracy diagnosis of foot rockers in gait. On the other side, although the 'substantial' to 'almost perfect' reliability of the FM pressure found in this study might formulate some questions about its actual reliability, it establishes the first scientific evidence to keep developing research on such overspread-used pressure platform. This way of measuring rocker duration has not yet been used in the pathological population so there are no clinically meaningful measures to compare.

Future research should establish normative values of these gait phases with these systems in order to compare with pathological gait (neurological gait, idiopathic toe walking, clubfoot, and others). Because this study focused on young, healthy, male adults, future research should consider the evaluation of the systems with children, women, elderly and populations with pathological disorders.

5. Conclusion

The current study indicates that the OptoGait system and the Freemed platform can accurately assess foot rockers in young, healthy men walking at a constant speed. The findings presented here might be extremely useful for therapists working on both gait retraining and identification of pathologies. The user-friendliness of both the OptoGait system and the Freemed pressure platform, as well as their proven accuracy *vs*. high-speed video analysis for foot rockers analysis, gives clinicians a precise tool to make decisions about the degree of change due to the normal variability of measuring between trials or sessions, which is especially important for early detection of walking pathologies.

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References

[1] J. Perry, J.M. Burnfield, Gait analysis. Normal and pathological function 2nd ed, J California: Slack (2010).

[2] M.W. Whittle, Gait analysis: an introduction, Butterworth-Heinemann2014.

[3] M. Burnfield, Gait analysis: normal and pathological function, Journal of Sports Science and Medicine 9(2) (2010) 353.

[4] T. Stöckel, R. Jacksteit, M. Behrens, R. Skripitz, R. Bader, A. Mau-Moeller, The mental representation of the human gait in young and older adults, J Frontiers in psychology 6 (2015) 943.

[5] K. Shah, M. Solan, E.J.O. Dawe, Trauma, The gait cycle and its variations with disease and injury, 34(3) (2020) 153-160.

[6] D.E. Westberry, J.R. Davids, R.B. Davis, M.C. de Morais Filho, Idiopathic toe walking: a kinematic and kinetic profile, Journal of Pediatric Orthopaedics 28(3) (2008) 352-358.

[7] C. Alvarez, M. De Vera, R. Beauchamp, V. Ward, A. Black, Classification of idiopathic toe walking based on gait analysis: development and application of the ITW severity classification, Gait and posture 26(3) (2007) 428-435.

[8] F. Garcia-Pinillos, P.A. Latorre-Roman, V.M. Soto-Hermoso, J.A. Parraga-Montilla, A. Pantoja-Vallejo, R. Ramirez-Campillo, et al., Agreement between the spatiotemporal gait parameters from two different wearable devices and high-speed video analysis, PLoS One 14(9) (2019) e0222872. https://www.ncbi.nlm.nih.gov/pubmed/31550296.

[9] B. Mariani, H. Rouhani, X. Crevoisier, K.J.G. Aminian, posture, Quantitative estimation of foot-flat and stance phase of gait using foot-worn inertial sensors, 37(2) (2013) 229-234.

[10] C. Balsalobre-Fernandez, H. Agopyan, J.-B. Morin, The Validity and Reliability of an iPhone App for Measuring Running Mechanics, Journal of Applied Biomechanics 33(3) (2017) 222-226. <Go to ISI>://WOS:000405759500007.

[11] A. Gomez Bernal, R. Becerro-de-Bengoa-Vallejo, M.E. Losa-Iglesias, Reliability of the OptoGait portable photoelectric cell system for the quantification of spatial-temporal parameters of gait in young adults, Gait Posture 50 (2016) 196-200. http://www.ncbi.nlm.nih.gov/pubmed/27644096.

[12] B. Szczepanowska-Wołowiec, P. Sztandera, I. Kotela, M.J.I.J.o.E.R. Zak, P. Health, Assessment of the Foot's Longitudinal Arch by Different Indicators and Their Correlation with the Foot Loading Paradigm in School-Aged Children: A Cross Sectional Study, 18(10) (2021) 5196.

[13] B. Szczepanowska-Wolowiec, P. Sztandera, I. Kotela, M.J.B.m.d. Zak, Feet deformities and their close association with postural stability deficits in children aged 10–15 years, 20(1) (2019) 1-9.

[14] W. Forczek, A. Masłoń, B. Frączek, M. Curyło, M. Salamaga, A.J.P.o. Suder, Does the first trimester of pregnancy induce alterations in the walking pattern?, 14(1) (2019) e0209766.

[15] M.M. Lee, C.H. Song, K.J. Lee, S.W. Jung, D.C. Shin, S.H. Shin, 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, Journal of physical therapy science 26(1) (2014) 81-85.

[16] D. Jaén-Carrillo, F. García-Pinillos, A. Cartón-Llorente, A.J. Almenar-Arasanz, J.A. Bustillo-Pelayo, L.E. Roche-Seruendo, Test–retest reliability of the OptoGait system for the analysis of spatiotemporal running gait parameters and lower body stiffness in healthy adults, Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology (2020) 1754337119898353.

[17] L. Correale, V.C. Pellino, L. Marin, M. Febbi, M. Vandoni, Comparison of an inertial measurement unit system and baropodometric platform for measuring spatiotemporal parameters and walking speed in healthy adults, Motor Control 25(1) (2020) 89-99.

[18] E. Von Elm, D.G. Altman, M. Egger, S.J. Pocock, P.C. Gøtzsche, J.P. Vandenbroucke, The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies, Annals of internal medicine 147(8) (2007) 573-577.

[19] K.E. Webster, J.E. Wittwer, J.A. Feller, Validity of the GAITRite® walkway system for the measurement of averaged and individual step parameters of gait, Gait & posture 22(4) (2005) 317-321.
[20] F. García-Pinillos, P.Á. Latorre-Román, R. Ramirez-Campillo, L.E. Roche-Seruendo, Agreement between spatiotemporal parameters from a photoelectric system with different filter settings and high-speed video analysis during running on a treadmill at comfortable velocity, Journal of biomechanics (2019).
[21] B. Hanley, C.B. Tucker, Reliability of the OptoJump Next System for Measuring Temporal Values in Elite Racewalking, Journal of strength and conditioning research (2019).
[22] SensorMedica, https://www.sensormedica.com/site/en/products/platforms-freemed z dn, (accessed 03/08/2022 2022).
[23] J.-F. Esculier, T. Silvini, L.J. Bouyer, J.-S. Roy, Video-based assessment of foot strike pattern and step rate is valid and reliable in runners with patellofemoral pain, Physical Therapy in Sport 29 (2018) 108-112.
[24] A. Pipkin, K. Kotecki, S. Hetzel, B. Heiderscheit, Reliability of a Qualitative Video Analysis for Running, J Orthop Sports Phys Ther 46(7) (2016) 556-61. http://www.ncbi.nlm.nih.gov/pubmed/27266886.
[25] T.G. McPoil, M.W. Cornwall, L. Dupuis, M. Cornwell, Variability of plantar pressure data. A comparison of the two-step and midgait methods, Journal of the American Podiatric Medical Association 89(10) (1999) 495-501.
[26] K.N. Radzak, A.M. Putnam, K. Tamura, R.K. Hetzler, C.D. Stickley, Asymmetry between lower limbs during rested and fatigued state running gait in healthy individuals, Gait Posture 51 (2017) 268-274. http://www.ncbi.nlm.nih.gov/pubmed/27842295.
[27] W. Hopkins, S. Marshall, A. Batterham, J. Hanin, Progressive statistics for studies in sports medicine and exercise science, Medicine Science in Sports Exercise 41(1) (2009) 3.
[28] T.K. Koo, M.Y. Li, A guideline of selecting and reporting intraclass correlation coefficients for reliability research, Journal of chiropractic medicine 15(2) (2016) 155-163.
[29] J. Cohen, Statistical power analysis, Current directions in psychological science 1(3) (1992) 98-101.
[30] J.M. Bland, D.G. Altman, Comparing methods of measurement: why plotting difference against standard method is misleading, The lancet 346(8982) (1995) 1085-1087.
[31] G. Atkinson, A.M. Nevill, Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine, Sports medicine 26(4) (1998) 217-238.
[32] M. Lee, C. Song, K. Lee, D. Shin, S.J.M.s.m.i.m.j.o.e. Shin, c. research, Agreement between the spatio-temporal gait parameters from treadmill-based photoelectric cell and the instrumented treadmill system in healthy young adults and stroke patients, 20 (2014) 1210.
[33] A. Healy, K. Linyard-Tough, N. Chockalingam, Agreement Between the Spatiotemporal Gait Parameters of Healthy Adults From the OptoGait System and a Traditional Three-Dimensional Motion Capture System, J Biomech Eng 141(1) (2019). http://www.ncbi.nlm.nih.gov/pubmed/30285079.
[34] K. Lienhard, D. Schneider, N.A. Maffiuletti, Validity of the Optogait photoelectric system for the assessment of spatiotemporal gait parameters, Med Eng Phys 35(4) (2013) 500-4. http://www.ncbi.nlm.nih.gov/pubmed/22818403.
[35] M.M. Lee, C.H. Song, K.J. Lee, S.W. Jung, D.C. Shin, S.H. Shin, 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, Journal of physical therapy science 26(1) (2014) 81-5. http://www.ncbi.nlm.nih.gov/pubmed/24567681.

TABLES

***Table 1**. Mean measurements and effect size of foot rockers in gait measured with OptoGait and Freemed and compared against values obtained with high-speed video analysis.*

Variable	OG (±SD)	SM FM (±SD)	VA (±SD)	OG vs VA Δ (%)	OG vs VA p-value^ (ES)	FM vs VA Δ (%)	FM vs VA p-value^ (ES)
Rocker 1 (ms)	116.66 (45.25)	155.22 (56.61)	123.39 (49.6)	-6.72 (13)	0.026* (0.14)	31.83 (17)	0.000* (0.07)
Rocker 2 (ms)	448.44 (104.49)	399.28 (101.305)	426.00 (122.28)	22.44 (50)	0.056 (0.26)	-26.72 (47)	0.047* (0.69)
Rocker 3+4 (ms)	329.75 (75.81)		348.72 (64.23)	-18.97 (37)	0.014* (0.81)		
Rocker 3 (ms)		323.33 (57.54)	275.44 (55.59)			47.89 (35)	0.000* (0.34)
Rocker 4 (ms)		36.50 (19.28)	73.28 (18.44)			-36.78 (1)	0.000* (2.46)

OG: OptoGait; SMFM: Freemed; VA: high-speed video analysis; SD: Standard deviation; Δ: Difference between measurements obtained from both systems; ES: Cohen's d effect size

^ calculated by pairwise mean comparison (t-test)

* $p < 0.05$

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Table 2. *Pearson coefficients and intraclass correlation coefficients (ICC [2,1]) for comparisons between foot rockers obtained from OptoGait and Freemed against high-speed video analysis.*

Variable		OG_R1	OG_R2	OG_R3+4	FM_R1	FM_R2	FM_R3	FM_R4
VA_R1	Pearson coefficient (r)	0.980*			0.793*			
	Sig.	0.000			0.000			
	ICC (95% CI)	0.980 (0.934 – 0.993)			0.857 (0.028 – 0.962)			
VA_R2	Pearson coefficient (r)		0.907*			0.915*		
	Sig.		0.000			0.000		
	ICC (95% CI)		0.949 (0.852 – 0.982)			0.930 (0.795 – 0.975)		
VA_R3+4	Pearson coefficient (r)			0.884*				
	Sig.			0.000				
	ICC (95% CI)			0.939 (0.777 – 0.979)				
VA_R3	Pearson coefficient (r)						0.912*	
	Sig.						0.000	
	ICC (95% CI)						0.816 (-0.136 – 0.959)	
VA_R4	Pearson coefficient (r)							0.382
	Sig.							0.117
	ICC (95% CI)							0.253 (-0.191 – 0.645)

VA_R1: first rocker measured with high-speed video analysis; VA_R2: second rocker measured with high-speed video analysis;VA_R3+4: third and fourth rockers measured with high-speed video analysis; VA_R3: third rocker measured with high-speed video analysis; VA_R4: fourth rocker measured with high-speed video analysis;OG_R1: first rocker measured with OptoGait; OG_R2:second rocker measured with OptoGait;OG_R3+4:third and fourth rockers measured with OptoGait; FM_R1: first rocker measured with Freemed; FM_R2: second rocker measured with Freemed; FM_R3: third rocker measured with Freemed; FM_R4: fourth rocker measured with Freemed; ICC: intraclass correlation coefficient; CI: Confidence interval

* $p < 0.05$

Table 3. *Bland & Altman Bias and 95% Limits of Agreement.*

Parameter	OG vs VA			FM vs VA		
	Bias (SD)	Lower LOA	Upper LOA	Bias (±SD)	Lower LOA	Upper LOA
Rocker 1 (ms)	6.72 (±11.69)	68.3722	255.3722	-31.83 (±26.19)	97.8798	312.3798
Rocker 2 (ms)	-22.44 (±46.51)	357.0104	797.0104	26.72 (±52.88)	330.7540	778.2540
Rocker 3+4 (ms)	18.97 (±29.42)	284.3362	563.5862	-	-	-
Rocker 3 (ms)	-	-	-	-47.89 (±20.66)	256.3245	445.8245
Rocker 4 (ms)	-	-	-	36.78 (±20.39)	67.7896	126.7896

OG: OptoGait; FM: Freemed; VA: high-speed video analysis; SD: Standard deviation; LOA: 95 Limit of agreement

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FIGURE CAPTIONS

Figure 1. Picture of OptoGait system on Freemed baropodometric platform for data collection.

Figure 2. Foot rockers diagram for analysis.

Figure 3. OG vs. VA differences between the measurements (systematic bias and random error) and the degree of agreement (95% limits of agreement) for rockers 1 (3.A), 2 (3.B) and 3+4 (3.C). The plot includes the mean difference (dotted line) and 95% limits of agreement (dashed line), along with the regression line (solid line).

Figure 4. FM vs. VA differences between the measurements (systematic bias and random error) and the degree of agreement (95% limits of agreement) for rockers 1 (4.A), 2 (4.B), 3 (4.C) and 4 (4.D). The plot includes the mean difference (dotted line) and 95% limits of agreement (dashed line), along with the regression line (solid line).

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Figure 2

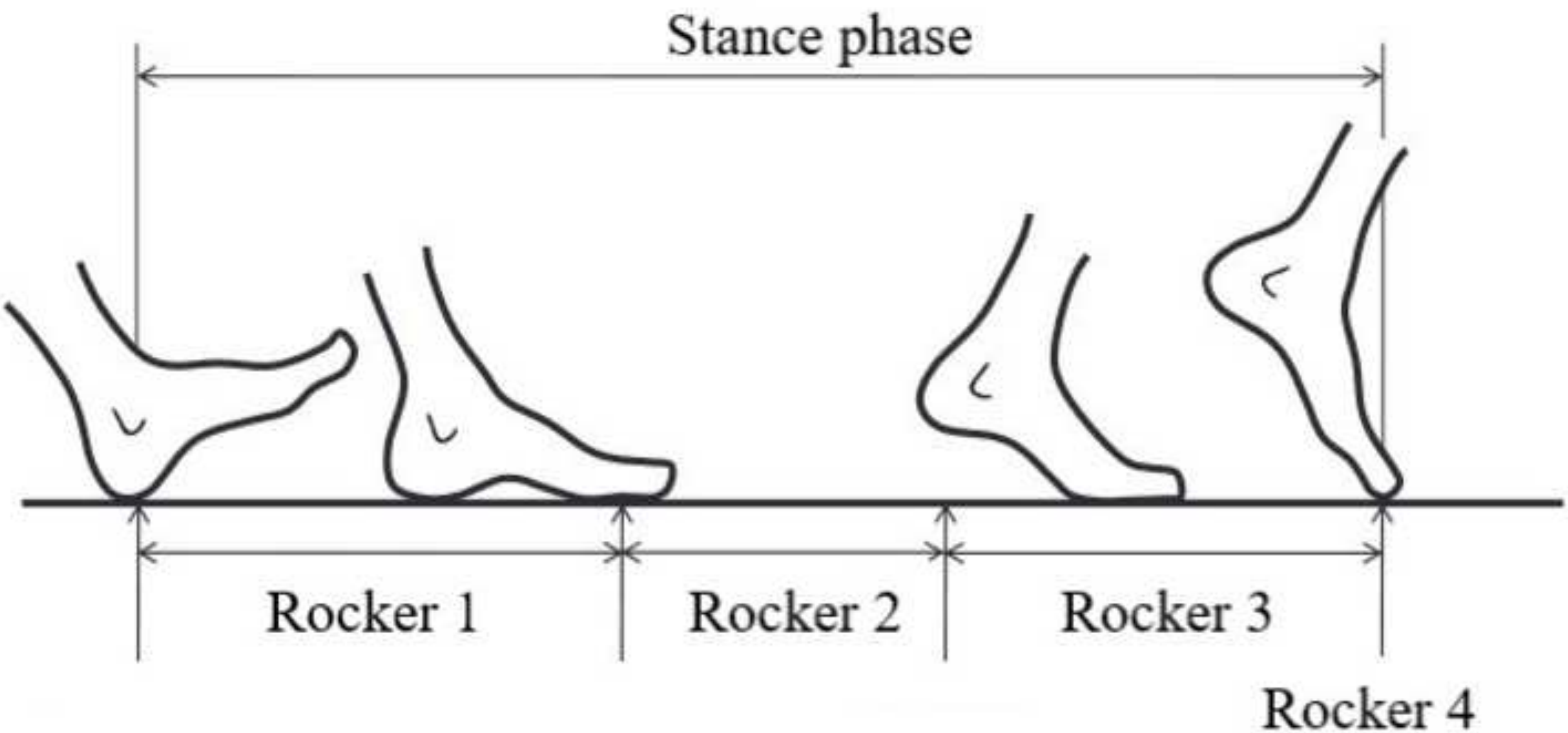

Figure 3

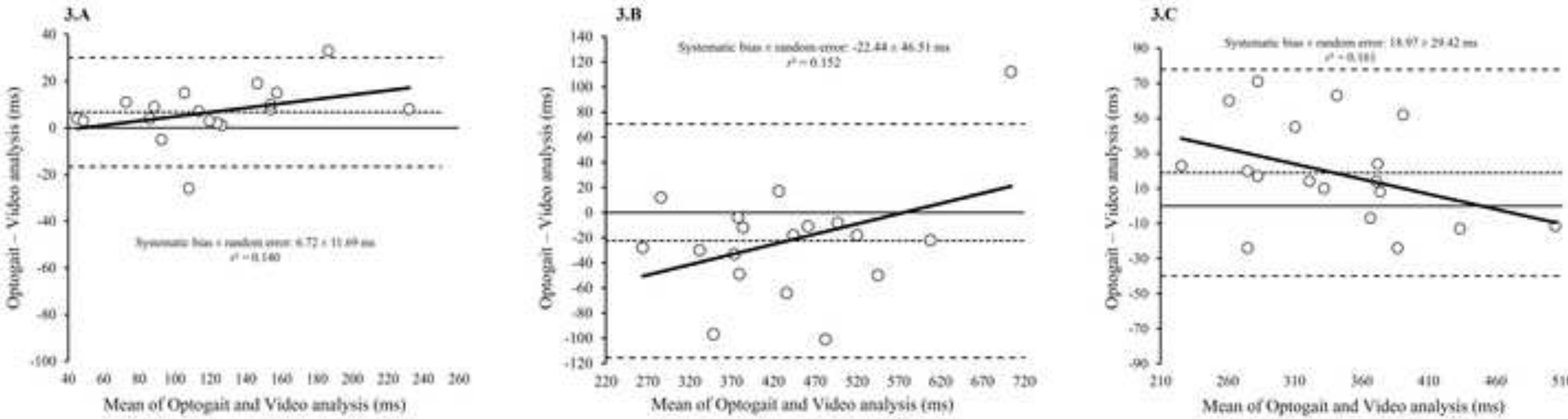
3.A
Systematic bias ± random error: 6.72 ± 11.69 ms
r² = 0.140
Optogait – Video analysis (ms)
Mean of Optogait and Video analysis (ms)
3.B
Systematic bias ± random error: -22.44 ± 46.51 ms
r² = 0.152
Optogait – Video analysis (ms)
Mean of Optogait and Video analysis (ms)
3.C
Systematic bias ± random error: 18.97 ± 29.42 ms
Optogait – Video analysis (ms)
Mean of Optogait and Video analysis (ms)

Figure 4

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