

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

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2 **measuring walking gait**

3 **ABSTRACT**

4 The gait cycle can be divided into four functional rocker units. Although the widespread use of  
5 the OptoGait (OG) system and the Freedmed (FM) platform, their accuracy has not been tested.  
6 An observational study was completed with eighteen healthy volunteers to determine the accuracy  
7 of OG and FM for overground walking gait analysis. The pairwise comparison between data  
8 obtained from OG, FM and high-speed video analysis revealed significant differences for most  
9 of the measurements ( $p < 0.05$ ). ICCs revealed an excellent absolute agreement between  
10 measurements (ICCs  $> 0.94$ ) for all measures for OG systems compared to video-analysis. When  
11 considering FM vs. video-analysis, ICCs showed good absolute agreement for rocker 1 (ICC =  
12 0.86) and 3 (ICC = 0.82), excellent for rocker 2 (ICC = 0.93) and poor (ICC  $< 0.5$ ) for rocker 4.  
13 Bland-Altman plots (95% limits of agreement) revealed heteroscedasticity of error for OG in all  
14 variables for foot rockers ( $r^2 > 0.1$ ) while no heteroscedasticity of error was found when using  
15 FM ( $r^2 < 0.1$ ). This study indicates that the OG system and the FM platform can provide consistent  
16 foot rockers values when walking at a constant velocity. The differences between the systems  
17 assessed and their agreement and consistency values advise against their interchangeable use.

18  
19 **KEYWORDS**

20 heel-off, pressure platform, rockers, testing

21

## 22 **1. Introduction**

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

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

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

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

47 Foot rockers analysis is not only key for gait acquisition, development, and retraining [6], but also  
48 it helps identify the severity of idiopathic toe walking [7]. Although the assessment of such events

49 seems to be important for clinicians in revealing variations between pathological and non-  
50 pathological gait, it has received very little attention from the scientific community.

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

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

## 74 **2. Methods**

### 75 *2.1. Experimental Approach to the problem*

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

### 81 *2.2. Participants*

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

### 88 *2.3. Procedures*

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

97 \*\*\*FIGURE 1 ABOUT HERE\*\*\*

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

### 102 *2.4. Material and Testing*

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

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

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

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

128

129

\*\*\*FIGURE 2 ABOUT HERE\*\*\*

130

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

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

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

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

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

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

### 138 2.5. Statistical analysis

139 Mean standard deviation ( $\pm$ SD) is used to represent descriptive statistics. All data were subjected  
140 to normal distribution and homogeneity tests, as established by the Saphiro-Wilk and Levene's  
141 tests, prior to analysis. A pairwise mean comparison (t-test) was performed comparing data from  
142 the OptoGait and Freemed systems as well as the high-speed video analysis. To evaluate  
143 consistency of the values, a Pearson correlation analysis was done between each rocker measured  
144 by OptoGait (R1-R2-R3) and Freemed (R1-R2-R3-R4) and VA. The following criteria were used  
145 to interpret the level of correlation between measurements:  $<0.1$  (trivial),  $0.1-0.3$  (small),  $0.3-0.5$   
146 (moderate),  $0.5-0.7$  (large),  $0.7-0.9$  (very large),  $0.9-1.0$  (almost perfect) [27]. Furthermore, intra  
147 class correlation coefficients (ICC) for rockers during walking were evaluated between systems  
148 (i.e., OG vs VA and FM vs VA). Following the principles stated by Koo and Li [28] and based  
149 on the characteristics of this experimental design, the authors conducted a “two-way random-  
150 effects” model (ICC [2,1]), “single measurement” type, and “absolute agreement” definition for  
151 the ICC measurement. To analyse absolute agreement, the benchmarks reported in [28] were  
152 considered to interpret the ICC: ICC  $< 0.5$  reflects ‘poor’,  $0.5-0.75$  ‘moderate’,  $0.75-0.90$  ‘good’,  
153 and  $> 0.90$  ‘excellent’ reliability. The magnitude of the differences was interpreted using Cohen’s  
154 d effect size (ES) [29], being reported as: trivial ( $<0.2$ ), small ( $0.2-0.49$ ), medium ( $0.5-0.79$ ), and  
155 large ( $\geq 0.8$ ) [29]. To analyse differences in foot rockers features between measurements (i.e., OG,  
156 FM, VA) and between systems (i.e., OG vs. VA and FM vs. VA), the Bland-Altman [30] limits

157 of agreement method (mean difference  $\pm$  1.96 SD) was used. Heteroscedasticity of error was  
158 defined as an  $r^2 > 0.1$ . All the statistical analyses have been done following Atkinson and Nevill  
159 recommendations for assessing reliability [31]. The level of significance used was  $p < 0.05$ . Data  
160 analysis was performed using the SPSS (version 21, SPSS Inc., Chicago, IL).

### 161 **3. Results**

162 Normal distribution and homogeneity, determined by the Shapiro-Wilk and Levene's test,  
163 respectively, were confirmed on all data before analysis ( $p > 0.05$ ). The pairwise comparison  
164 between data obtained from OG, FM and VA revealed significant differences for most of the  
165 measurements (Table 1). Despite OG seems to significantly overestimate rocker 1 and rocker 3+4  
166 when comparing to VA ( $p < 0.05$ ), the effect size for rocker 1 was trivial (0.14) and for rocker  
167 3+4 was large (0.81). When comparing FM vs. VA, it revealed significant differences for all the  
168 measurements ( $p < 0.05$ ) and an effect size for rocker 1 considered trivial, medium for rocker 2,  
169 small for rocker 3, and large for rocker 4.

170 **\*\*\*TABLE 1 ABOUT HERE\*\*\***

171 However, the consistency between measurements (Table 2) was almost perfect ( $r > 0.9$ ) when  
172 comparing rocker 1 and 2 values obtained with OG and VA and when comparing values for rocker  
173 2 and 3 using FM and VA. Moreover, very large ( $r > 0.7$ ) agreements were found for rocker 3+4  
174 when comparing OG vs. VA and for rocker 1 when FM vs. VA were considered. The ICCs also  
175 revealed a 'good' to 'excellent' association between measurements (ICCs  $> 0.84$ ) for all the values  
176 for both systems compared to VA, excepting rocker 4 when considering FM vs. VA, which  
177 exhibited 'poor' agreement (ICC  $< 0.5$ ).

178 **\*\*\*TABLE 2 ABOUT HERE\*\*\***

179 Through Bland-Altman plots, figure 3 and figure 4 show the differences between the  
180 measurements obtained from OG and VA, and FM and VA, respectively, as well as the degree  
181 of agreement (95% limits of agreement) (Table 3). When using OG, heteroscedasticity of error



182 was found in all variables for foot rockers ( $r^2 > 0.1$ ) (Figure 3). However, no heteroscedasticity  
183 of error was found when using FM ( $r^2 < 0.1$ ) (Figure 4).

184 \*\*\*TABLE 3 ABOUT HERE\*\*\*

185 \*\*\*FIGURE 3 ABOUT HERE\*\*\*

186 \*\*\*FIGURE 4 ABOUT HERE\*\*\*

#### 187 **4. Discussion**

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

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

206 OG validity for assessing spatiotemporal variables for both treadmill walking [32] and running  
207 [20], and overground walking [33, 34] has been previously investigated. These studies dealt  
208 with the OG's validity to measure spatiotemporal parameters such as contact time, which is  
209 directly related to the stance phase in walking and, thus, to the different foot rockers here

210 mentioned. Although gait analysis was assessed employing OG and comparing values against  
211 different reference systems (i.e., VA and instrumented treadmills), the analysis of foot rockers  
212 was omitted. Despite the fact that in the present study foot rockers were analysed during  
213 overground walking, our findings ( $ICC > 0.9$ ) are endorsed by those found in a previous study  
214 [20] where the authors reported high ICCs ( $ICC = 0.981$ ) when identifying contact time  
215 employing VA. The slight differences between the values obtained in both studies may be  
216 attributed to the different protocols. While in our study participants were asked to walk  
217 overground, participants ran on a treadmill in the previous study [20]. When measuring foot  
218 rockers using FM and comparing to those measurements recorded with VA, good to excellent  
219 absolute agreement ( $ICC > 0.81$ ) was found for rockers 1, 2 and 3.

220 The observed findings are consistent with results previously reported for spatiotemporal  
221 characteristics in healthy individuals [11, 35]. While Gomez-Bernal et al. evaluated the OG's  
222 reliability for spatiotemporal parameters analysis in treadmill walking [11] and Lee et al. asked  
223 their participants to walk three times at a comfortable speed on a sidewalk, the current study  
224 shows the of the OG system for foot rockers analysis in overground walking (rocker 1:  $r =$   
225  $0.98$ ,  $ICC = 0.98$ ; rocker 2:  $r = 0.91$ ,  $ICC = 0.95$ ; rocker 3+4:  $r = 0.88$ ,  $ICC = 0.94$ ). Similarly,  
226 FM seems to provide 'good' to 'excellent' accurate measures for the analysis of foot rockers,  
227 except for rocker 4 (i.e., 'poor' =  $ICC < 0.5$ ). Therefore, the accuracy of FM seems to be lower  
228 than the exhibited by the OG system. This might be explained given the differing frequencies  
229 the systems are able to use when recording data ( $OG = 1000$  Hz and  $FM = 350$  Hz). Based on  
230 the discrepancies between systems and their accuracy values, their interchangeable use when  
231 analysing gait parameters should be avoided.

232 Even though the current study gives some light on the usage of the OG and FM systems as  
233 accurate instruments for the evaluation of foot rockers, there are certain limitations to consider.  
234 First, although participants were asked to walk overground at their desired speed, the laboratory  
235 setting should be taken into account when analysing these results. Then, on one side, the 'almost  
236 perfect' reliability of the OptoGait system showed by the current results will provide future  
237 researchers enough evidence to use such system for the accuracy diagnosis of foot rockers in  
238 gait. On the other side, although the 'substantial' to 'almost perfect' reliability of the FM

239 pressure found in this study might formulate some questions about its actual reliability, it  
240 establishes the first scientific evidence to keep developing research on such overspread-used  
241 pressure platform. This way of measuring rocker duration has not yet been used in the  
242 pathological population so there are no clinically meaningful measures to compare.

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

## 248 **5. Conclusion**

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

257

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260

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365

## 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 ( $\pm$ SD)	FM ( $\pm$ SD)	VA ( $\pm$ SD)	OG vs VA	OG vs VA	FM vs VA	FM vs VA
				$\Delta$ (%)	p-value <sup>^</sup> (ES)	$\Delta$ (%)	p-value <sup>^</sup> (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;  $\Delta$ : Difference between measurements obtained from both systems; ES: Cohen's d effect size

<sup>^</sup> 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 ( $\pm$ SD)	Lower LOA	Upper LOA
Rocker 1 (ms)	6.72 ( $\pm$ 11.69)	68.3722	255.3722	-31.83 ( $\pm$ 26.19)	97.8798	312.3798
Rocker 2 (ms)	-22.44 ( $\pm$ 46.51)	357.0104	797.0104	26.72 ( $\pm$ 52.88)	330.7540	778.2540
Rocker 3+4 (ms)	18.97 ( $\pm$ 29.42)	284.3362	563.5862	-	-	-
Rocker 3 (ms)	-	-	-	-47.89 ( $\pm$ 20.66)	256.3245	445.8245
Rocker 4 (ms)	-	-	-	36.78 ( $\pm$ 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 Freedmed 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**

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1 **Absolute agreement and consistency of the OptoGait system and Freedmed platform for**  
2 **measuring walking gait**

3 **ABSTRACT**

4 The gait cycle can be divided into ~~three~~four functional rocker units. Although the widespread use  
5 of the OptoGait (OG) system and the Freedmed (FM) platform, their accuracy has not been tested.  
6 An observational study was completed with eighteen healthy volunteers to determine the accuracy  
7 of OG and FM for overground walking gait analysis. The pairwise comparison between data  
8 obtained from OG, FM and high-speed video analysis revealed significant differences for most  
9 of the measurements ( $p < 0.05$ ). ICCs revealed an excellent absolute agreement between  
10 measurements (ICCs  $> 0.94$ ) for all measures for OG systems compared to video-analysis. When  
11 considering FM vs. video-analysis, ICCs showed good absolute agreement for rocker 1 (ICC =  
12 0.86) and 3 (ICC = 0.82), excellent for rocker 2 (ICC = 0.93) and poor (ICC  $< 0.5$ ) for rocker 4.  
13 Bland-Altman plots (95% limits of agreement) revealed heteroscedasticity of error for OG in all  
14 variables for foot rockers ( $r^2 > 0.1$ ) while no heteroscedasticity of error was found when using  
15 ~~SM-FM~~ ( $r^2 < 0.1$ ). This study indicates that the OG system and the FM platform can provide  
16 ~~adequate-consistent~~ foot rockers values when walking at a constant velocity. The differences  
17 between the systems assessed and their ~~accuracy-agreement and consistency~~ values advise against  
18 their interchangeable use.

19

20 **KEYWORDS**

21 heel-off, pressure platform, rockers, testing

22

## 23 **1. Introduction**

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

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

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

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

48 Foot rockers analysis is not only key for gait acquisition, development, and retraining [6], but also  
49 it helps identify the severity of idiopathic toe walking [7]. Although the assessment of such events

50 seems to be important for clinicians in revealing variations between pathological and non-  
51 pathological gait, it has received very little attention from the scientific community.

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

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

## 75 **2. Methods**

### 76 *2.1. Experimental Approach to the problem*

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

## 82 *2.2. Participants*

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

## 89 *2.3. Procedures*

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

98 \*\*\*FIGURE 1 ABOUT HERE\*\*\*

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

## 103 *2.4. Material and Testing*

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

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

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

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

129

130 \*\*\*FIGURE 2 ABOUT HERE\*\*\*

131

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

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

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

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

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

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

### 139 2.5. Statistical analysis

140 Mean standard deviation ( $\pm$ SD) is used to represent descriptive statistics. All data were subjected  
141 to normal distribution and homogeneity tests, as established by the Saphiro-Wilk and Levene's  
142 tests, prior to analysis. A pairwise mean comparison (t-test) was performed comparing data from  
143 the OptoGait and Freemed systems as well as the high-speed video analysis. To evaluate  
144 consistency of the values, a Pearson correlation analysis was done between each rocker measured  
145 by OptoGait (R1-R2-R3) and Freemed (R1-R2-R3-R4) and VA. The following criteria were used  
146 to interpret the level of correlation between measurements:  $<0.1$  (trivial),  $0.1-0.3$  (small),  $0.3-0.5$   
147 (moderate),  $0.5-0.7$  (large),  $0.7-0.9$  (very large),  $0.9-1.0$  (almost perfect) [27]. Furthermore, intra  
148 class correlation coefficients (ICC) for rockers during walking were evaluated between systems  
149 (i.e., OG vs VA and FM vs VA). Following the principles stated by Koo and Li [28] and based  
150 on the characteristics of this experimental design, the authors conducted a “two-way random-  
151 effects” model (ICC [2,1]), “single measurement” type, and “absolute agreement” definition for  
152 the ICC measurement. To analyse absolute agreement, the benchmarks reported in [28] were  
153 considered to interpret the ICC:  $ICC < 0.5$  reflects ‘poor’,  $0.5-0.75$  ‘moderate’,  $0.75-0.90$  ‘good’,  
154 and  $> 0.90$  ‘excellent’ reliability. The magnitude of the differences was interpreted using Cohen’s  
155 d effect size (ES) [29], being reported as: trivial ( $<0.2$ ), small ( $0.2-0.49$ ), medium ( $0.5-0.79$ ), and  
156 large ( $\geq 0.8$ ) [29]. To analyse differences in foot rockers features between measurements (i.e., OG,  
157 FM, VA) and between systems (i.e., OG vs. VA and FM vs. VA), the Bland-Altman [30] limits



158 of agreement method (mean difference  $\pm$  1.96 SD) was used. Heteroscedasticity of error was  
159 defined as an  $r^2 > 0.1$ . All the statistical analyses have been done following Atkinson and Nevill  
160 recommendations for assessing reliability [31]. The level of significance used was  $p < 0.05$ . Data  
161 analysis was performed using the SPSS (version 21, SPSS Inc., Chicago, IL).

### 162 3. Results

163 Normal distribution and homogeneity, determined by the Shapiro-Wilk and Levene's test,  
164 respectively, were confirmed on all data before analysis ( $p > 0.05$ ). The pairwise comparison  
165 between data obtained from OG, ~~SM-FM~~ and VA revealed significant differences for most of the  
166 measurements (Table 1). Despite OG seems to significantly overestimate rocker 1 and rocker 3+4  
167 when comparing to VA ( $p < 0.05$ ), the effect size for rocker 1 was trivial (0.14) and for rocker  
168 3+4 was large (0.81). When comparing FM vs. VA, it revealed significant differences for all the  
169 measurements ( $p < 0.05$ ) and an effect size for rocker 1 considered trivial, medium for rocker 2,  
170 small for rocker 3, and large for rocker 4.

171 \*\*\*TABLE 1 ABOUT HERE\*\*\*

172 However, the consistency between measurements (Table 2) was almost perfect ( $r > 0.9$ ) when  
173 comparing rocker 1 and 2 values obtained with OG and VA and when comparing values for rocker  
174 2 and 3 using FM and VA. Moreover, very large ( $r > 0.7$ ) agreements were found for rocker 3+4  
175 when comparing OG vs. VA and for rocker 1 when FM vs. VA were considered. The ICCs also  
176 revealed a 'good' to 'excellent' association between measurements (ICCs  $> 0.84$ ) for all the values  
177 for both systems compared to VA, excepting rocker 4 when considering FM vs. VA, which  
178 exhibited 'poor' agreement (ICC  $< 0.5$ ).

179 \*\*\*TABLE 2 ABOUT HERE\*\*\*

180 Through Bland-Altman plots, figure 3 and figure 4 show the differences between the  
181 measurements obtained from OG and VA, and FM and VA, respectively, as well as the degree  
182 of agreement (95% limits of agreement) (Table 3). When using OG, heteroscedasticity of error

183 was found in all variables for foot rockers ( $r^2 > 0.1$ ) (Figure 3). However, no heteroscedasticity  
184 of error was found when using SM-FM ( $r^2 < 0.1$ ) (Figure 4).

185 \*\*\*TABLE 3 ABOUT HERE\*\*\*

186 \*\*\*FIGURE 3 ABOUT HERE\*\*\*

187 \*\*\*FIGURE 4 ABOUT HERE\*\*\*

#### 188 **4. Discussion**

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

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

207 OG validity for assessing spatiotemporal variables for both treadmill walking [32] and running  
208 [20], and overground walking [33, 34] has been previously investigated. These studies dealt  
209 with the OG's validity to measure spatiotemporal parameters such as contact time, which is  
210 directly related to the stance phase in walking and, thus, to the different foot rockers here

211 mentioned. Although gait analysis was assessed employing OG and comparing values against  
212 different reference systems (i.e., VA and instrumented treadmills), the analysis of foot rockers  
213 was omitted. Despite the fact that in the present study foot rockers were analysed during  
214 overground walking, our findings ( $ICC > 0.9$ ) are endorsed by those found in a previous study  
215 [20] where the authors reported high ICCs ( $ICC = 0.981$ ) when identifying contact time  
216 employing VA. The slight differences between the values obtained in both studies may be  
217 attributed to the different protocols. While in our study participants were asked to walk  
218 overground, participants ran on a treadmill in the previous study [20]. When measuring foot  
219 rockers using FM and comparing to those measurements recorded with VA, good to excellent  
220 absolute agreement ( $ICC > 0.81$ ) was found for rockers 1, 2 and 3.

221 The observed findings are consistent with results previously reported for spatiotemporal  
222 characteristics in healthy individuals [11, 35]. While Gomez-Bernal et al. evaluated the OG's  
223 reliability for spatiotemporal parameters analysis in treadmill walking [11] and Lee et al. asked  
224 their participants to walk three times at a comfortable speed on a sidewalk, the current study  
225 shows the of the OG system for foot rockers analysis in overground walking (rocker 1:  $r =$   
226  $0.98$ ,  $ICC = 0.98$ ; rocker 2:  $r = 0.91$ ,  $ICC = 0.95$ ; rocker 3+4:  $r = 0.88$ ,  $ICC = 0.94$ ). Similarly,  
227 FM seems to provide 'good' to 'excellent' accurate measures for the analysis of foot rockers,  
228 except for rocker 4 (i.e., 'poor' =  $ICC < 0.5$ ). Therefore, the accuracy of FM seems to be lower  
229 than the exhibited by the OG system. This might be explained given the differing frequencies  
230 the systems are able to use when recording data ( $OG = 1000$  Hz and ~~SM-FM~~ =  $350$  Hz). Based  
231 on the discrepancies between systems and their accuracy values, their interchangeable use when  
232 analysing gait parameters should be avoided.

233 Even though the current study gives some light on the usage of the OG and FM systems as  
234 accurate instruments for the evaluation of foot rockers, there are certain limitations to consider.  
235 First, although participants were asked to walk overground at their desired speed, the laboratory  
236 setting should be taken into account when analysing these results. Then, on one side, the 'almost  
237 perfect' reliability of the OptoGait system showed by the current results will provide future  
238 researchers enough evidence to use such system for the accuracy diagnosis of foot rockers in  
239 gait. On the other side, although the 'substantial' to 'almost perfect' reliability of the FM

240 pressure found in this study might formulate some questions about its actual reliability, it  
241 establishes the first scientific evidence to keep developing research on such overspread-used  
242 pressure platform. This way of measuring rocker duration has not yet been used in the  
243 pathological population so there are no clinically meaningful measures to compare.

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

## 249 **5. Conclusion**

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

258

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261

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## 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		FM vs VA	
				Δ (%)	p-value <sup>^</sup> (ES)	Δ (%)	p-value <sup>^</sup> (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; SM-FM: Freemed; VA: high-speed video analysis; SD: Standard deviation; Δ: Difference between measurements obtained from both systems; ES: Cohen's d effect size

<sup>^</sup> 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 ( $\pm$ SD)	Lower LOA	Upper LOA
Rocker 1 (ms)	6.72 ( $\pm$ 11.69)	68.3722	255.3722	-31.83 ( $\pm$ 26.19)	97.8798	312.3798
Rocker 2 (ms)	-22.44 ( $\pm$ 46.51)	357.0104	797.0104	26.72 ( $\pm$ 52.88)	330.7540	778.2540
Rocker 3+4 (ms)	18.97 ( $\pm$ 29.42)	284.3362	563.5862	-	-	-
Rocker 3 (ms)	-	-	-	-47.89 ( $\pm$ 20.66)	256.3245	445.8245
Rocker 4 (ms)	-	-	-	36.78 ( $\pm$ 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 Freedmed 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.- SFM 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).







