Original Article

Institution of MECHANICAL ENGINEERS

Journal of SPORTS ENGINEERING AND TECHNOLOGY

Proc IMechE Part P:
J Sports Engineering and Technology
1–7

Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1754337120977409
journals.sagepub.com/home/pip
SAGE

Absolute reliability and validity of the OptoGait™ system to measure spatiotemporal gait parameters during running

Felipe García-Pinillos[1], Pedro A Latorre-Román[2], Jose M Chicano-Gutiérrez[3], Emilio J Ruiz-Malagón[3], Juan A Párraga-Montilla[2] and Luis E Roche-Seruendo[4]

Abstract
The biomechanics of walking and running, in both ground and treadmill conditions, have been extensively analysed and important differences have been reported. Despite some previous studies having examined the validity and reliability of the OptoGait™ system for measuring gait characteristics during walking, no previous works have determined the reliability and validity of this system while running on a treadmill. Therefore, this study aimed to determine the absolute reliability (within-subject variation) and evaluate the concurrent validity of the OptoGait™ system for measuring spatiotemporal variables while running at a comfortable speed by comparing data with a highly accurate system of measuring those parameters (i.e. video analysis at 1000 Hz). Forty-nine endurance runners performed a running protocol on a treadmill at a comfortable speed. Two systems were used to collect data: OptoGait™ system and high-speed video analysis at 1000 Hz. The coefficient of variation (CV) was calculated as a measure of absolute reliability. The OptoGait™ system reported a CV range between 2.2% and 11.4% for spatiotemporal parameters, while the video analysis showed a CV range between 0.02% and 9.9%. To determine concurrent validity, intra class correlation coefficients (ICC) and pairwise comparisons of means (t-test) were calculated between data from both systems. Although the paired *t*-test demonstrated significant differences between systems, a high level of agreement (ICC > 0.89) was obtained in spatiotemporal parameters between systems. When compared to a high-speed video analysis at 1000 Hz, the results indicate that the OptoGait™ system is a reliable and valid tool to measure spatiotemporal gait characteristics while running on a treadmill at a comfortable speed.

Keywords
Gait, kinematic, runners, video analysis

Date received: 19 December 2019; accepted: 9 November 2020

Introduction

A growing interest in analysing gait characteristics during running seems to be justified since spatiotemporal parameters have been related to both risk of injury[1,2] and athletic performance.[3–6] While previous methods of analysis have generally required well-equipped research laboratories, recently, there has been a move to produce low-cost, portable gait analysis equipment. In that context, a simple system (i.e. OptoGait™ system) based on the communication between two photoelectric cells, each composed of 96 LEDS, has gained popularity among sport scientists and clinicians.

More and more research has used the OptoGait™ system for measuring spatiotemporal gait characteristics during running.[7–9] This system has become very popular among clinicians and researchers. As an example, previous papers focused on determining the validity of other devices have used the OptoGait™ system as

[1]Department of Physical Education, Sports and Recreation, Universidad de La Frontera, Temuco, Chile
[2]Department of Corporal Expression, University of Jaen, Jaen, Spain
[3]Department of Physical Education and Sport, Universidad de Granada, Granada, España
[4]Universidad San Jorge, Villanueva de Gállego, Zaragoza, Spain

Corresponding author:
Felipe García-Pinillos, Department of Physical Education, Sports and Recreation, Universidad de La Frontera, Calle Uruguay, 1980, Temuco, 4811230, Chile.
Email: fegarpi@gmail.com

a 'gold-standard' for measuring spatiotemporal parameters during running.[10,11]

Some previous studies have analysed the reliability and validity of the OptoGait system™ for measuring spatiotemporal parameters of gait. For example, two previous works compared spatiotemporal parameters obtained from OptoGait™ with GAITRite™ systems,[12,13] whereas other previous work[14] focused on the comparison with spatiotemporal parameters obtained from a treadmill-based gait analysis (i.e. instrumented treadmill). Likewise, a previous study analysed the agreement between the spatiotemporal gait parameters calculated from the OptoGait™ system and a three-dimensional motion capture system.[15] The test-retest reliability of the OptoGait™ system has also been determined in a previous study[16] in which 126 participants were assessed during walking. All those papers have reported strong concurrent validity and reliability during walking. However, none of those works has determined the reliability and validity of this system while running on a treadmill, which implies some differences compared to walking (e.g. the lack of flight time [FT][17]) and over ground running.[18]

Additionally, the reliability and validity of a similar system (i.e. OptoJump™) for measuring temporal parameters have also been determined. Hanley and Tucker[19] compared temporal parameters in racewalkers using the OptoJump™ system versus high-speed video analysis in both over ground and treadmill settings, while Ammann et al.[20] determined the validity of the ground contact time (CT) obtained from the OptoJump™ system compared with high-speed video analysis during running on an indoor track. The OptoJump™ and OptoGait™ systems are commercially available and use the same hardware, but different software. Both systems work at 1000 Hz with the same spatial resolution (1.04 cm). Nevertheless, some between-system differences must be taken into consideration. First, the OptoGait™ uses a software that allows for analysing the walking gait by recognising double support, whereas the OptoJump™ system does not. Second, the OptoGait™ system can be considered as a medical device (i.e. it is certified for medical use), which allows the user to test in clinical environments, while the OptoJump™ system has not been certified as a medical device. Therefore, the validity and reliability of the OptoGait™ or OptoJump™ systems for measuring spatiotemporal parameters while running on a treadmill remain unknown.

The validity and reliability of a gait analysis system are essential to determine whether results are due to changes in gait pattern or simply systematic measurement errors. Therefore, the aim of the current study is to determine the absolute reliability (within-subject variation) and evaluate the concurrent validity of the OptoGait™ system for measuring spatiotemporal variables while running at a comfortable speed by comparing data with a highly accurate system of measuring those parameters (i.e. video analysis at 1000 Hz). It is hypothesised that the OptoGait™ system is a reliable and valid tool to measure spatiotemporal gait characteristics (i.e. CT, flight time [FT], step length [SL] and step frequency [SF]) during running.

Methods

Participants

A group of 49, 44 men and 5 women, amateur endurance runners (age: 26 ± 8 years; height: 1.74 ± 0.07 m; body mass: 71 ± 10 kg) voluntarily participated in this study. All participants met the inclusion criteria: (1) older than 18 years old, (2) able to run 10 km in less than 50 min, (3) not suffering from any injury in the 6 months prior to data collection. After receiving detailed information on the objectives and procedures of the study, each participant signed an informed consent form in order to participate, which complied with the ethical standards of the World Medical Association's Declaration of Helsinki (2013). It was made clear that the participants were free to leave the study at any time. The study was approved by the Institutional Review Board.

Procedures

Participants were individually tested on one specific day. Prior to all testing, participants refrained from intense physical activity for at least 48 h and all tests were at least 3 h after eating. Tests were performed with the participants' usual training shoes to measure their typical performance.

Participants performed a running protocol on a motorised treadmill (WOODWAY Pro XL, Woodway, Inc., Waukesha, WI, USA). The initial speed was set at 8 $km \cdot h^{-1}$, and speed increased by 1 $km \cdot h^{-1}$ every minute until participants felt comfortable. Then, running speed was fixed (i.e. self-selected comfortable running speed: 11.7 ± 1.3 $km \cdot h^{-1}$). Since previous studies[21,22] on human locomotion have shown that accommodation to running on a treadmill occurs in ~6–8 min, an 8 min accommodation program was performed at that self-selected running speed. Immediately after the accommodation interval and maintaining the same running speed, a 30 s recording period started. The slope of the treadmill was maintained at 0% during the entire protocol.

Materials and testing

For descriptive purposes, height (m) and body mass (kg) were measured using a precision stadiometer and scale, SECA 222 and 634, respectively (SECA, Corp., Hamburg, Germany).

The following spatiotemporal parameters were measured while running: CT (seconds): time from when the foot contacts the ground to when the toes lift off the ground; FT (seconds): time from toe-off to initial ground contact of consecutive footfalls (e.g. right-left); SL (centimetres): distance between two consecutive contacts measured from forefoot to forefoot; and SF (steps per minute): number of ground contact events per minute. Two different systems were used to measure those parameters, the OptoGait™ system and high-speed video analysis (1000 Hz). Both systems have the same temporal accuracy (±1 ms). For the analysis of temporal parameters (CT and FT), the right leg was always the analysed leg in order to control potential influencing factors (i.e. asymmetry[23]). Further information about the systems is noted below:

- The OptoGait™ system (Optogait; Microgate, Bolzano, Italy) detects any interruptions in the light connection between the transmitter bar and receiver bar and it measures both CT and FT with a precision of 1/1000 s. The two parallel bars of the device system were placed on the side edges of the treadmill at the same level as the contact surface and the default filter setting of 0_0 (Gait R.in filter:0 and Gait R.out filter:0) was accepted. This setting means that CT begins once more than 0 LEDs were activated (i.e. when at least 1 LED was activated) and finished once the number of LEDs activated returned to 0. This set up has shown to provide the smallest bias for temporal parameters in racewalking.[19] Spatiotemporal parameters (i.e. CT, FT, SL and SF) were measured for every step during 30 s for each participant.
- Video analysis: Two-dimensional video data were simultaneously collected at 1000 Hz using a high-speed camera (Imaging Source DFK 33UX174, The Imaging Source Europe GmbH; Germany). Range of interest (ROI) was adjusted to achieve 1000 fps (784×144 resolution). Two-dimensional video analysis has been suggested as a reliable[24,25] and valid[26] system to assess running kinematics. This procedure was based on the guidelines provided by a previous work.[27] The camera was placed perpendicular to the treadmill from a posterior view at 2 m from the centre of the treadmill and at a height of 0.80 m, and 30 s videos were recorded for each participant. Then, videos were analysed using the open licence software Kinovea (version 0.8.27), and spatiotemporal parameters were determined. Data were exported to a spreadsheet in.xml format and processed in Excel. The CT and FT were calculated by identifying the initial contact and take-off frames, while counting frames in-between. SL and SF were calculated as follows in equations (1)–(4):

(1) $Step\ time\ (ST,\ in\ seconds) = FT\ (s) + CT\ (s),$
(2) $SF\ (steps\ per\ second,\ sps) = 1/ST\ (s)$
(3) $SF\ (steps\ per\ minute,\ spm) = 60\ x\ SF\ (s)$
(4) $SL\ (m) = running\ speed\ (m{\cdot}min^{-1})\ /\ SF\ (spm)$

Statistical analysis

Descriptive statistics are represented as mean standard deviation (SD). Tests of normal distribution and homogeneity, determined by the Shapiro-Wilk and Levene's test, respectively, were conducted on all data before analysis. The coefficient of variation (CV, %) was calculated as a measure of absolute reliability, since it represents the within-subject variation ($CV = SD/mean*100$),[28,29] and it was calculated on an individual basis. To determine concurrent validity, a Pearson correlation analysis was performed between spatiotemporal parameters from the OptoGait™ system and video analysis. The following criteria were adopted to interpret the magnitude of correlations between measurement variables: < 0.1 (trivial), 0.1–0.3 (small), 0.3–0.5 (moderate), 0.5–0.7 (large), 0.7–0.9 (very large) and 0.9–1.0 (almost perfect).[30] Intra class correlation coefficients (ICC) were also calculated between systems (OptoGait™ vs video analysis) for CT, FT, SL and SF during running. Based on the characteristics of this experimental design and following the guidelines reported by Koo and Li,[31] the authors decided to conduct a "two-way random-effects" model (ICC [2,k]), "mean of measurements" type, and "absolute" definition for the ICC measurement. The interpretation of the ICC was based on the benchmarks reported by a previous study[32]: ICC < 0 (poor), 0–0.20 (slight), 0.21–0.40 (fair), 0.41–0.60 (moderate), 0.61–0.80 (substantial), and > 0.81 (almost perfect). Pairwise comparisons of means (t-test) were also conducted between data from the two systems. The magnitude of the differences between values was also interpreted using the Cohen's d effect size (*ES*) (between-group differences).[33] Effect sizes are reported as: trivial (< 0.2), small (0.2–0.49), medium (0.5–0.79), and large ($\geqslant 0.8$).[33] Finally, Bland-Altman plots (i.e. limits of agreement method, mean difference ± 1.96 SD)[34] were constructed to examine the presence of systematic and proportional bias between the measured (i.e. video analysis at 1000 Hz) and estimated values (i.e. OptoGait™ system) of spatiotemporal parameters during running. The level of significance used was $p < 0.05$. Data analysis was performed using SPSS (version 23, SPSS Inc., Chicago, Ill).

Results

Reliability

Table 1 shows the CV (in %) as a measure of absolute reliability of spatiotemporal parameters while running from both systems (i.e. OptoGait™ vs high-speed video analysis). For the OptoGait™ system, CV ranged between 2.2% and 11.4% (CT: 2.6%; FT: 11.4%; SF: 2.6%; SL: 2.2%), whereas for the video analysis, CV ranged between 0.02% and 9.9% (CT: 2.6%; FT: 9.9%; SF: 1.8%; SL: 0.02%).

Table 1. Mean magnitude of coefficient of variation (CV, %) of spatiotemporal parameters obtained from two different systems (OptoGait™ vs High-speed video analysis at 1000 Hz).

Variables	OptoGait™	High-speed video analysis
	CV (%)	CV (%)
CT (s)	2.64 (1.15)	2.56 (1.68)
FT (s)	11.39 (5.40)	9.93 (6.75)
SF (spm)	2.55 (1.18)	1.78 (0.51)
SL (cm)	2.18 (0.58)	0.018 (0.005)

CT: contact time; FT: flight time; SF: step frequency; SL: step length.

Validity

Table 2 shows descriptive values and a comparative analysis between systems. Despite small differences between systems (~0.003 s in CT, ~0.006 s in FT, ~2.1 spm in SF, and ~0.9 cm in SL), the paired *t*-test demonstrated significant differences between those systems in every parameter (FT, $p < 0.001$; SF, $p = 0.003$; SL, $p = 0.019$), except for CT ($p = 0.070$). Nevertheless, the Cohen's d values indicate trivial ES (ES < 0.2) for those comparisons.

In order to reinforce the comparative analysis, a Pearson correlation analysis was conducted and ICCs between systems were calculated (Table 3). Very large correlations ($r > 0.83$, $p < 0.001$) were obtained in CT, FT, SF and SL between both systems. Additionally, the ICC reported a high level of agreement (ICC > 0.89) between systems in all spatiotemporal parameters analysed.

Through Bland-Altman plots, Figure 1 shows the differences between the two systems (systematic bias and random error) and the degree of agreement between the two systems (95% limits of agreement). When comparing the video analysis system to the OptoGait™ system, these plots revealed small systematic biases (CT: 0.002 s; FT: –0.006 s; SF: 2.10 spm; SL: –0.97 cm) and random errors (CT: 0.008 s; FT: 0.008 s; SF: 4.68 spm; SL: 2.78 cm) for the spatiotemporal parameters while running at a comfortable self-selected speed on the treadmill.

Discussion

This study aimed at determining the reliability and validity of the OptoGait™ system for measuring spatiotemporal variables while running at a comfortable speed compared to data from a high-speed video analysis at 1000 Hz. The main finding of the current work is that the OptoGait™ system provided reliable spatiotemporal data, showing a strong concurrent validity as compared to the high-speed video analysis.

Both systems showed a high absolute reliability in terms of CV, as indicated by previous studies,[28,29] with CV lower than 3% in CT, SL and SF, whereas higher CVs (10–12%) were obtained in FT. The authors suggest that higher CVs in FT are related to the short duration of this phase while running at a comfortable velocity (i.e. –0.09 s) since CV equals SD/mean*100. Overall, these results are in line with those reported by previous studies.[12,14,16] Gomez Bernal et al.[16] analysed the gait of 126 participants while walking, each 2 weeks apart, concluding that the OptoGait™ system produces reliable measures for spatiotemporal parameters of gait in both intra- and inter-session (CV –6% in CT, SF and SL). Likewise, in a study in which twenty healthy young adults were asked to walk three times on a walkway at a comfortable speed,[12] the OptoGait™ system showed a strong reliability with CV ~1–4% in CT, SF and SL. Despite methodological differences (i.e. walking vs running, over ground vs treadmill, speed and type of reliability), the results seem to be consistent with previous studies and, therefore, the current study highlights the absolute reliability, in terms of CV (%), of the OptoGait™ system to measure spatiotemporal parameters while running on a treadmill at a comfortable speed.

Regarding the validity of the OptoGait™ system to measure spatiotemporal gait characteristics, some points must be considered to properly interpret the results and make comparisons with previous studies. The first point that must be taken into consideration is the gold standard or reference system that was used in those previous studies. Previous works have compared spatiotemporal parameters obtained from the OptoGait™ system with GAITRite™,[12,13] treadmill-based gait analysis,[14] three-dimensional motion capture system,[15] and high-speed video analysis at 500 Hz[19] and 1000 Hz.[20] The second aspect that must be considered is the protocol performed during these studies. Apart from one study,[20] the rest of the aforementioned works analysed the validity of the system while walking, whereas the current study was conducted while running at a self-selected speed. As for the study by

Table 2. Means comparison of spatiotemporal parameters obtained from two different systems (OptoGait™ vs High-speed video analysis at 1000 Hz).

Variable	OptoGait™	High-speed video analysis	Difference (Δ)	*p*-value	Effect size
CT (s)	0.270 (0.031)	0.267 (0.028)	0.003	0.070	0.101
FT (s)	0.087 (0.028)	0.093 (0.025)	−0.006	< 0.001	−0.196
SF (spm)	168.91 (8.43)	166.81 (7.69)	2.10	0.003	0.048
SL (cm)	115.93 (12.41)	116.89 (12.50)	−0.96	0.019	−0.065

Δ: difference between systems (OptoGait™ - Video analysis); CT: contact time; FT: flight time; SF: step frequency; SL: step length.

Table 3. Pearson correlation analysis (r) and intraclass correlation coefficients (ICC) between spatiotemporal parameters obtained from OptoGait™ versus High-speed video analysis during running at comfortable speed.

Variables	Coefficient (r)	p-value	ICC (95% CI)
CT	0.969	< 0.001	0.981 (0.965–0.989)
FT	0.965	< 0.001	0.967 (0.853–0.987)
SF	0.835	< 0.001	0.893 (0.783–0.944)
SL	0.975	< 0.001	0.986 (0.974–0.993)

CT: contact time; FT: flight time; SF: step frequency; SL: step length; ICC: intraclass correlation coefficients; CI: confidence interval.

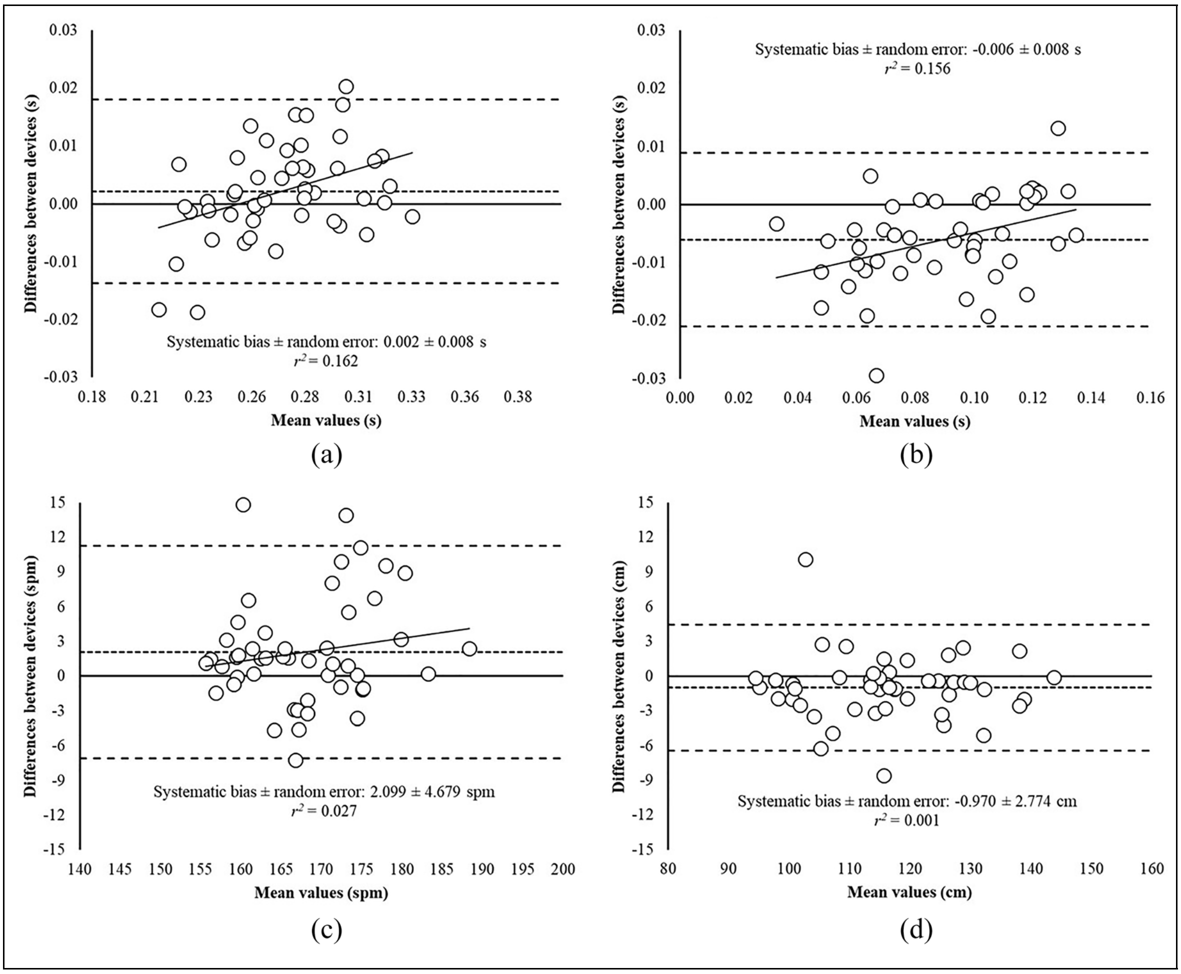

Figure 1. Bland-Altman plots for the measurement of spatiotemporal parameters during running at self-selected comfortable speed for both systems (OptoGait™ vs high-speed video analysis): (a) contact time (ms), (b) flight time (s), (c) step frequency (spm), and (d) step length (cm). The plot includes the mean difference (dotted line) and 95% limits of agreement (dashed lined), along with the regression line (solid line).

Ammann et al.,[20] different running speeds were considered with the lowest speed (i.e. $15 \pm 2.5\,\text{km·h}^{-1}$) much higher than the self-selected speed in the current work (i.e. $11.7 \pm 1.3\,\text{km·h}^{-1}$). The third point that must be taken into account is the variables controlled during those previous works. The FT does not exist during walking and the only study including running conditions[20] just considered CT, so it makes comparisons difficult. Finally, the last point that must be considered is the filter setting within the OptoGait™ software. Despite some previous studies[15,19,35] having analysed the influence of different filter settings within the OptoGait™ software on the level of agreement with other systems, the current study accepted the default filter setting (i.e. Gait R.in filter:0 and Gait R.out filter:0).

Despite differences, the results provided in those previous studies are consistent, by pointing to the OptoGait™ system as a valid device to measure spatiotemporal gait characteristics during walking. In this context, the current study provides some insights into the validity of the OptoGait™ system to measure spatiotemporal parameters (i.e. CT, FT, SL and SF) while running at a comfortable speed. This study not only supports the findings of Ammann et al.[20] by concluding that the OptoGait™ system is valid to measure CT while running on treadmill, but it also tests the validity of this system to measure other spatiotemporal parameters such as FT, SL and SF, reporting small systematic biases and random errors and very high ICCs and Pearson coefficients (> 0.9).

An important consideration is that reliability data were obtained from an analysis based on within-subject variation (CV), rather than on different days (i.e. test-re-test). Therefore, the current reliability statistics might not generalise to runs performed several days apart. Notwithstanding this limitation, the strength of this study is the usage of a high-speed video analysis at 1000 Hz as the gold standard with a high frequency and high resolution, installed at surface level, which allowed great accuracy for determining spatiotemporal parameters while running at a comfortable speed – a condition that had not yet been tested.

Conclusions

The results indicate that the OptoGait ™ system is a reliable and valid tool to measure spatiotemporal gait characteristics while running on treadmill at a comfortable speed as compared to the high-speed video analysis at 1000 Hz.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Felipe García-Pinillos https://orcid.org/0000-0002-7518-8234
Jose M Chicano-Gutiérrez https://orcid.org/0000-0001-5835-8265
Emilio J Ruiz-Malagón https://orcid.org/0000-0003-1228-5413

References

1. Schubert AG, Kempf J and Heiderscheit BC. Influence of stride frequency and length on running mechanics: a systematic review. *Sports Health* 2014; 6(3): 210–217.
2. Luedke LE, Heiderscheit BC, Williams DSB, et al. Influence of step rate on shin injury and anterior knee pain in high school runners. *Med Sci Sports Exerc* 2016; 48(7): 1244–1250.
3. Barnes KR and Kilding AE. Running economy: measurement, norms, and determining factors. *Sport Med Open* 2015; 1(1): 8.
4. Tartaruga MP, Brisswalter J, Peyré-Tartaruga LA, et al. The relationship between running economy and biomechanical variables in distance runners. *Res Q Exerc Sport* 2012; 83(3): 367–375.
5. Mooses M, Mooses K, Haile DW, et al. Dissociation between running economy and running performance in elite Kenyan distance runners. *J Sports Sci* 2015; 33(2): 136–144.
6. Anderson T. Biomechanics and running economy. *Sport Med* 1996; 22(2): 76–89.
7. Roche-Seruendo LE, García Pinillos F, Auria-Martin I, et al. Effects of different percentages of body weight support on spatiotemporal step characteristics during running. *J Sports Sci* 2018; 36(13): 1441–1446.
8. García-Pinillos F, Latorre-Román PÁ, Ramírez-Campillo R, et al. How does the slope gradient affect spatiotemporal parameters during running? Influence of athletic level and vertical and leg stiffness. *Gait Posture* 2018; 68: 72–77.
9. Roche-Seruendo LE, García-Pinillos F, Haicaguerre J, et al. Lack of influence of muscular performance parameters on spatio-temporal adaptations with increased running velocity. *J Strength Cond Res* 2018; 32(2): 409–415.
10. García-Pinillos F, Roche-Seruendo LE, Marcen-Cinca N, et al. Absolute reliability and concurrent validity of the Stryd system for the assessment of running stride kinematics at different velocities. *J Strenght Cond Res.* Epub ahead of print 17 May 2018. DOI: 10.1519/JSC.0000000000002595.
11. Balsalobre-Fernández C, Agopyan H and Morin J-B. The validity and reliability of an iPhone app for measuring running mechanics. *J Appl Biomech* 2017; 33(3): 222–226.
12. Lee MM, Song CH, Lee KJ, et al. 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. *J Phys Ther Sci* 2014; 26(1): 81–85.
13. Lienhard K, Schneider D and Maffiuletti NA. Validity of the Optogait photoelectric system for the assessment of spatiotemporal gait parameters. *Med Eng Phys* 2013; 35(4): 500–504.
14. Lee M, Song C, Lee K, et al. Agreement between the spatio-temporal gait parameters from treadmill-based photoelectric cell and the instrumented treadmill system in healthy young adults and stroke patients. *Med Sci Monit* 2014; 20: 1210–1219.
15. Healy A, Linyard-Tough K and Chockalingam N. Agreement between the spatiotemporal gait parameters of healthy adults from the OptoGait system and a traditional three-dimensional motion capture system. *J Biomech Eng* 2019; 141(1): 1–4.
16. Gomez Bernal A, Becerro-de-Bengoa-Vallejo R and Losa-Iglesias ME. Reliability of the OptoGait portable photoelectric cell system for the quantification of spatial-temporal parameters of gait in young adults. *Gait Posture* 2016; 50: 196–200.

17. Lohman EB, Balan Sackiriyas KS and Swen RW. A comparison of the spatiotemporal parameters, kinematics, and biomechanics between shod, unshod, and minimally supported running as compared to walking. *Phys Ther Sport* 2011; 12: 151–163.
18. Riley PO, Dicharry J, Franz J, et al. A kinematics and kinetic comparison of overground and treadmill running. *Med Sci Sports Exerc* 2008; 40(6): 1093–1100.
19. Hanley B and Tucker CB. Reliability of the OptoJump next system for measuring temporal values in elite race-walking. *J Strength Cond Res* 2019; 33(12): 3438–3443.
20. Ammann R, Taube W and Wyss T. Accuracy of PARTwear inertial sensor and Optojump optical measurement system for measuring ground contact time during running. *J Strength Cond Res* 2016; 30(7): 2057–2063.
21. Schieb DA. Kinematic accommodation of novice treadmill runners. *Res Q Exerc Sport* 1986; 57(1): 1–7.
22. Lavcanska V, Taylor NF and Schache AG. Familiarization to treadmill running in young unimpaired adults. *Hum Mov Sci* 2005; 24(4): 544–557.
23. Radzak KN, Putnam AM, Tamura K, et al. Asymmetry between lower limbs during rested and fatigued state running gait in healthy individuals. *Gait Posture* 2017; 51: 268–274.
24. Dingenen B, Barton C, Janssen T, et al. Test-retest reliability of two-dimensional video analysis during running. *Phys Ther Sport* 2018; 33: 40–47.
25. Pipkin A, Kotecki K, Hetzel S, et al. Reliability of a qualitative video analysis for running. *J Orthop Sport Phys Ther* 2016; 46(7): 556–561.
26. Esculier JF, Silvini T, Bouyer LJ, et al. Video-based assessment of foot strike pattern and step rate is valid and reliable in runners with patellofemoral pain. *Phys Ther Sport* 2018; 29: 108–112.
27. Padulo J, Chamari K and Ardigò LP. Walking and running on treadmill: the standard criteria for kinematics studies. *Muscles Ligaments Tendons J* 2014; 4(2): 159–162.
28. Atkinson G and Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sport Med* 1998; 26(4): 217–238.
29. Hopkins WG. Measures of reliability in sports medicine and science. *Sport Med* 2000; 30(1): 1–15.
30. Hopkins WG, Marshall SW, Batterham AM, et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009; 41(1): 3–13.
31. Koo TK and Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med* 2016; 15(2): 155–163.
32. Landis JR and Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; 33(1): 159–174.
33. Cohen J. *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.
34. Bland JM and Altman DG. Comparing methods of measurement: why plotting difference against standard method is misleading. *Lancet* 1995; 346(8982): 1085–1087.
35. García-Pinillos F, Latorre-Román PÁ, Ramirez-Campillo R, et al. 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. *J Biomech* 2019; 93: 213–219.