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Reliability of the RunScribe™ system to determine kinematic variables of the pelvis during locomotion at different speeds

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Purpose: The aim of this study was to determine the reliability of the RunScribe™ system to measure kinematic variables of the pelvis during walking and running. *Methods*: In this study, a treadmill protocol was implemented where the participants ($n = 23$) completed 3 sets of 1 minute at 5, 10 and 15 km/h. *Results*: All the recorded measurements during walking reported a low reliability with coefficients of variation (CV) greater than 10% in all variables and small-moderate intraclass correlation coefficient (ICC) (<0.6) in seven out of ten variables. Similarly, the CVs reported in running were greater than 10%, except for the maximum angular rate in the obliquity of the pelvis and the vertical oscillation that together with the angular velocity variables showed almost perfect ICCs (>0.92). *Conclusions*: Therefore, the data obtained suggests that the RunScribe™ system with 3 IMUs does not provide reliable metrics about the kinematics of the pelvis during locomotion (i.e., walking and running).

Key words: *RunScribe™, reliability, kinematic variables, walking, running*

1. Introduction

Biomechanics seems to play an outstanding role in endurance running. Concerning running-related injuries, level of performance competence, sex or foot-strike pattern have been suggested as injury risk indicators [10], [18], [19]. From a performance perspective, variables such contact times, leg-stiffness, vertical oscillation, kinematics parameters of the pelvis in different planes (i.e., tilt, obliquity, rotation and maximum angular rate) or stride frequency are strongly related to running economy (RE) (i.e., the energy demand for a given submaximal running speed). Therefore, monitoring these variables should allow practitioners to know their strengths and weakness.

However, the main concern about assessing running biomechanics is its accessibility. Traditionally, biomechanical evaluations have required great technological displays (i.e., motion capture systems, force platforms, etc.) in a laboratory setting, which seems to be neither ecological nor economical. However, an increase in the use of portable technological resources such as inertial measurement units (IMUs), accelerometers or photoelectric cells have facilitated such task outside the laboratory. These systems make it possible to measure physiological and biomechanical variables by offering real-time feedback helping to improve athletic performance, prevent injuries and improve motivation [17].

IMUs allow for the estimation of linear acceleration and angular velocity of the movements being able

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to process up to three axes of movement simultaneously (frontal, sagittal and transverse) [3]. Commercial devices such as RunScribe™ or Stryd™ report feedback about spatio-temporal characteristics during walking and running, applicable to both technical re-education and the quantification of the training load with variables already consolidated in other endurance sports (e.g., cycling) such as power or cadence [4], [9]. Therefore, it seems crucial to analyze the reliability and validity of these devices to determine its functionality.

The RunScribe™ system (Scribe Labs, Inc., San Francisco, CA, USA) is a device based on 9 axes (three--axis gyroscope, three-axis accelerometer and three-axis magnetometer) with a sampling frequency of 500 Hz. This system is able to record spatio-temporal, kinetic and kinematic parameters of walking and running to obtain information on the efficiency and symmetry of the running pattern [4]. Previous studies indicated that RunScribe™ is a valid system for measuring spatio-temporal parameters during treadmill running reporting a high degree of agreement with a high-speed video analysis [4]. In addition, it is a valid and a reliable system to determine variations in the spatio-temporal, kinetic and kinematic parameters in different conditions [6], [12].

At its first appearance in the market, RunScribe™ consisted of two pedometers, for both footwear. The system could be attached either in the laces of the footwear or in the heel, what can also be a reason for disagreement in certain variables [4]. In 2020, RunScribe™ included a new update with the addition of a third sensor to be located in the sacrum to record kinematics parameters of the pelvis in different planes. Specifically, it provides the following metrics: anteversion, retroversion, obliquity and rotation as well as their respective maximum angular rate. To date, despite being a widely used system for gait and running analysis, there is no scientific evidence on its reliability, which is a key aspect in the functionality of its use.

Therefore, the aim of this study was to analyze the reliability of the new RunScribe ™ system, based on three IMUs, to evaluate the kinematics of the pelvis during walking and running. Based on the articles mentioned about the RunScribe ™ system [4], [12], it is hypothesized that the new update of the device provides reliable metrics on the kinematics of the pelvis during locomotion (walking and running).

2. Materials and methods

Subjects

A group of 23 physically active subjects, 6 women and 17 men (age = 22.7 ± 2.6 years; body mass = 69.1 ± 11.7 kg; height = 1.72 ± 0.10 m; training = 6.9 ± 2.4 h/week) volunteered to participate in this study. All participants trained at least three days a week and were familiar with treadmill walking and running. None

Fig. 1. Sacral and footwear RunScribe ™ sensors

of the participants reported any physical limitation, health problem or musculoskeletal injury that could compromise their participation. Before starting the study, the participants were informed of the procedures, signed a written informed consent and, finally, filled out a sociodemographic questionnaire. The study protocol adhered to the principles of the Declaration of Helsinki and was approved by the Institutional review board.

Materials and testing

- Anthropometry, height [m] and body mass [kg] of the participants were obtained using a SECA 222 stadiometer (SECA, Corp., Hamburg, Germany) and an Inbody 230 bioimpedance meter (Inbody Seúl, Corea), respectively.
- Kinematics. The kinematic parameters were obtained using the RunScribe™ inertial measurement unit (Scribe Lab., Inc., San Francisco, CA, USA). This IMU combines an accelerometer, a gyroscope and a triaxial magnetometer that record at a speed of 500 Hz. Following the recommendations of García-Pinillos et al. [4], two RunScribe ™ devices were attached to the laces of the footwear. A third RunScribe™ device was added to the waistband of the pants at the height of the sacrum following the recommendations established by the manufacturer. Before data collection, the system was calibrated flat and once mounted. The values of each kinematic parameter (i.e., tilt, obliquity, rotation, maximum angular rate and vertical oscillation) were collected automatically by the platform (www.runscribe.com) and from there, copied to an Excel sheet for subsequent analysis.

Procedures

Each participant was evaluated only once. The participants were asked not to practice any vigorous physical activity in the 48 hours prior to data collection and to follow their usual sleep and diet patterns. To perform the test, the participants put on their usual training shoes and clothes. Participants completed a treadmill (WOODWAY Pro XL, Woodway, Inc., Waukesha, WI, USA) running protocol. Lavcanska et al. [14] and Schieb [16] reported that a minimum time of about 6 to 8 minutes is required for the runner to familiarize its locomotion on the treadmill. Therefore, in order to reduce variability in the running pattern, participants began with a 10-minute warm-up at a self-selected comfortable speed. Once familiarized, the participants completed 3 sets of 1 minute at 5, 10 and 15 km/h. After a 5-minute break, to avoid any disturbance in the running pattern induced by fatigue, the participants returned to complete a second attempt of the protocol identical to the first one. The recording was made in the last 30 seconds of each bout, where the subject was already adapted to the running speed.

Statistical analyses

Data is presented as means, standard deviations and ranges. The normal distribution of the data was confirmed using the Shapiro–Wilk test ($P > 0.05$). *T*-tests for dependent samples were used to compare the magnitude of the variables between the two blocks (test-retest). The magnitude of the differences was also expressed as a standardized mean difference (Cohen's *d* effect size [*d*]). The criterion to interpret the magnitude of *d* was the following: trivial (<0.20), small (0.20–0.59), moderate (0.60–1.19), large (1.20–2.00) and very large (>2.00) [7]. Reliability was evaluated through the standard error (SE) and the coefficient of variation (CV, expressed in %) with its corresponding 95% confidence interval (CI) [7]. Reliability was defined as acceptable with a CV < 10% [1]. Additionally, the intraclass correlation coefficient (ICC, model 3.1) between the two blocks and for each of the variables evaluated was provided following the recommendations proposed by Koo and Li [11]. For its interpretation, the following cut-off points were considered [13]: ICC <0 (poor), 0–0.20 (trivial), 0.21–0.40 (small), 0.41–0.60 (moderate), 0.61–0.80 (substantial), and >0.81 (almost perfect). The 95% CI for these ICCs was also provided. All reliability evaluations were performed using custom spreadsheets [8]. Statistical significance was set at an α level of 0.05.

3. Results

The test-retest reliability data for the kinematic variables measurements reported by the RunScribe ™ system during walking (5 km/h) and running (10 and 15 km/h) conditions are shown in Table 1.

Reliability during walking (5 km/h) condition

For the walking condition, no significant differences were observed between the blocks for the controlled variables ($P \geq 0.076$), except for the minimum and maximum rotation of the pelvis ($P = 0.044$ and 0.019, respectively). However, the magnitude of the differences was trivial to small ($d \leq 0.59$) with the only exception of the maximum rotation of the pelvis ($d = 0.63$).

Table 1. Reliability of the different variables related to the kinematics of the pelvis recorded by the RunScribe ™ system at different walking speeds and running on a treadmill (5, 10 and 15 km/h)

Variables	Velocity [km/h)]	Block 1 (Mean, SD)	Block 2 (Mean, SD)	P	ES	SE	CV (CI 95%)
Minimum pelvic tilt [º]	5	–3.8 (0.9)	–3.7 (1.0)	0.655	0.08	0.48	–12.8 (–9.6 to –19.17)
	10	–8.3 (8.7)	–7.8 (8.4)	0.813	0.06	6.89	–85.6 (–66.2 to –121.2)
	15	–7.1 (11.1)	–8.4 (8.8)	0.479	0.13	6.00	–77.2 (–59.1 to –111.5)
Maximum pelvic tilt [º]	5	3.7 (1.1)	3.3 (1.3)	0.096	0.33	0.67	19.1 (14.4 to 28.7)
	10	7.4 (8.5)	8.6 (12.0)	0.591	0.12	7.68	95.8 (74.1 to 135.6)
	15	12.8 (8.3)	9.6 (7.3)	0.067	0.41	5.30	47.8 (36.6 to 69.0)
Minimum pelvic obliquity [º]	5	–5.9 (1.8)	–6.1 (1.8)	0.529	0.11	0.91	–15.1 (–11.4 to –22.8)
	10	–7.1 (3.4)	–6.9 (3.4)	0.522	0.06	1.06	–15.23 (–11.8 to –21.6)
	15	–11.1 (4.9)	–12.8 (6.8)	0.024	0.28	2.23	–18.6 (–14.3 to –26.9)
Maximum pelvic obliquity [º]	5	5.6 (1.7)	5.9 (2.0)	0.506	0.15	1.23	21.5 (16.1 to 32.2)
	10	7.4 (3.0)	7.1 (3.0)	0.454	0.09	1.20	16.6 (12.8 to 23.5)
	15	11.7 (5.6)	12.3 (5.7)	0.301	0.10	1.80	15.1 (11.5 to 21.6)
Minimum pelvic rotation [º]	5	–4.4 (1.3)	–5.3 (2.0)	0.044	0.5	1.16	–23.9 (–17.9 to –35.8)
	10	–5.5 (1.3)	–5.8 (1.8)	0.287	0.17	0.83	–14.6 (–11.3 to –20.8)
	15	–7.1 (1.8)	–7.6 (2.4)	0.110	0.27	1.09	–14.8 (–11.3 to –21.4)
Maximum pelvic rotation [º]	5	4.3 (1.2)	5.3 (1.9)	0.019	0.63	1.18	24.5 (18.4 to 36.7)
	10	5.6 (1.5)	6.0 (2.0)	0.154	0.23	0.93	16.0 (12.4 to 22.6)
	15	7.4 (2.4)	8.4 (2.7)	0.010	0.37	1.07	13.5 (10.3 to 19.5)
Tilt maximum angular rate [º/s]	5	56.4 (46.1)	50.1 (26.0)	0.444	0.17	24.46	45.9 (34.5 to 68.9)
	10	349.3 (241.6)	344.3 (253.4)	0.739	0.02	49.85	14.4 (11.1 to 20.3)
	15	399 (244.7)	377.4 (234.2)	0.236	0.09	57.48	14.8 (11.3 to 21.4)
Obliquity maximum angular rate [º/s]	5	80.0 (57.5)	72.0 (22.4)	0.505	0.18	35.24	46.4 (34.8 to 69.5)
	10	240.7 (125.4)	248.8 (126.2)	0.181	0.06	19.86	8.1 (6.3 to 11.5)
	15	258.7 (113.6)	265.8 (105.9)	0.317	0.07	22.57	8.6 (6.6 to 12.4)
Rotation maximum angular rate [º/s]	5	40.7 (19.9)	42.2 (13.9)	0.701	0.09	11.53	27.8 (20.9 to 41.7)
	10	145.6 (78.7)	143.3 (79.2)	0.739	0.03	23.18	16.1 (12.4 to 22.7)
	15	158.9 (76.5)	165.3 (92.9)	0.421	0.08	25.38	15.7 (12.0 to 22.6)
Vertical oscillation [cm]	5	24.6 (4.6)	26.5 (2.8)	0.076	0.49	2.97	11.6 (8.7 to 17.4)
	10	9.1 (1.9)	9.4 (1.9)	0.028	0.15	0.42	4.5 (3.5 to 6.4)
	15	6.4 (1.8)	6.7 (1.7)	0.071	0.13	0.41	6.2 (4.7 to 8.9)

SD – standard deviations, P – *p*-value, ES – Cohen's *d* effect size, SE – standard error, CV – coefficient of variation, CI – 95%, 95% confidence interval.

The measurements recorded for walking reported low reliability with CV greater than 10% in all variables, the lowest being 11.6% for the vertical oscillation variable and 46.4% the highest CV for the pelvic obliquity angular rate variable.

Reliability during running (10 and 15 km/h) condition

When running at 10 km/h no significant differences were observed between the blocks ($P \geq 0.154$), except for the vertical oscillation ($P = 0.028$), and the magnitude of these differences also ranged from trivial to small ($d \leq 0.23$). At 15 km/h significant differences were only found between the blocks for the variables of minimum obliquity ($P = 0.024$) and maximum rotation of the pelvis ($P = 0.010$), with magnitudes from trivial to small ($d \leq 0.42$) for those differences.

Regarding CVs reported in running, only the angular rate in the obliquity of the pelvis and the vertical oscillation were less than 10% at 10 km/h (8.1% and 4.5%, respectively) and at 15 km/h (8,6% and 6.2%, respectively). The rest of the variables shows higher CVs (CV ≥ 13.5%).

To support these data, in Table 2, the ICC (CI 95%) is shown as a test-retest reliability measure for the different variables related to pelvic kinematics recorded by the RunScribe ™ system.

ICC walking condition

During the walking condition, seven out of ten variables analyzed showed small-moderate ICC (<0.6), while the remaining three, maximum and minimum pelvic tilt and minimum pelvic obliquity, showed substantial ICC (ICC 0.61–0.80).

Table 2. Intraclass Correlation Coefficient (ICC), as a test-retest reliability measure, for the different variables related to pelvic kinematics recorded by the RunScribe ™ system during walking and running on a treadmill (5, 10 and 15 km/h)

Variables	Velocity [km/h]	Block 1 (Mean, SD)	Block 2 (Mean, SD)	ICC	CI 95%
Minimum pelvic tilt [°]	5	–3.8 (0.9)	–3.7 (1.0)	0.77	0.49–0.91
	10	–8.3 (8.7)	–7.8 (8.4)	0.37	–0.04–0.67
	15	–7.1 (11.1)	–8.4 (8.8)	0.66	0.33–0.85
Maximum pelvic tilt [°]	5	3.7 (1.1)	3.3 (1.3)	0.71	0.38–0.88
	10	7.4 (8.5)	8.6 (12.0)	0.48	0.09–0.74
	15	12.8 (8.3)	9.6 (7.3)	0.56	0.18–0.80
Minimum pelvic obliquity [°]	5	–5.9 (1.8)	–6.1 (1.8)	0.76	0.46–0.90
	10	–7.1 (3.4)	–6.9 (3.4)	0.91	0.80–0.96
	15	–11.1 (4.9)	–12.8 (6.8)	0.87	0.71–0.95
Maximum pelvic obliquity [°]	5	5.6 (1.7)	5.9 (2.0)	0.57	0.14–0.82
	10	7.4 (3.0)	7.1 (3.0)	0.85	0.69–0.94
	15	11.7 (5.6)	12.3 (5.7)	0.91	0.79–0.96
Minimum pelvic rotation [°]	5	–4.4 (1.3)	–5.3 (2.0)	0.55	0.13–0.81
	10	–5.5 (1.3)	–5.8 (1.8)	0.75	0.49–0.89
	15	–7.1 (1.8)	–7.6 (2.4)	0.75	0.49–0.89
Maximum pelvic rotation [°]	5	–4.4 (1.3)	–5.3 (2.0)	0.55	0.13–0.81
	10	5.6 (1.5)	6.0 (2.0)	0.74	0.48–0.88
	15	7.4 (2.4)	8.4 (2.7)	0.84	0.64–0.93
Tilt maximum angular rate [°/])	5	56.4 (46.1)	50.1 (26.0)	0.60	0.20–0.83
	10	349.3 (241.6)	344.3 (253.4)	0.97	0.92–0.99
	15	399 (244.7)	377.4 (234.2)	0.95	0.88–0.98
Obliquity maximum angular rate [°/s]	5	80.0 (57.5)	72.0 (22.4)	0.37	–0.10–0.71
	10	240.7 (125.4)	248.8 (126.2)	0.98	0.95–0.99
	15	258.7 (113.6)	265.8 (105.9)	0.96	0.91–0.98
Rotation maximum angular rate [°/s]	5	40.7 (19.9)	42.2 (13.9)	0.57	0.16–0.82
	10	145.6 (78.7)	143.3 (79.2)	0.92	0.82–0.97
	15	158.9 (76.5)	165.3 (92.9)	0.92	0.81–0.97
Vertical oscillation [cm]	5	24.6 (4.6)	26.5 (2.8)	0.40	–0.06–0.73
	10	9.1 (1.9)	9.4 (1.9)	0.95	0.90–0.98
	15	6.4 (1.8)	6.7 (1.7)	0.95	0.89–0.98

SD – standard deviations, CI 95%, 95% confidence interval.

ICC running condition

In running both at 10 and 15 km/h the metrics related to pelvic tilt showed moderate to substantial ICC (>0.37). The variables related to the obliquity and rotation of the pelvis showed ICC between substantial and almost perfect (>0.74), whereas the maximum angular rate and vertical oscillation variables present almost perfect ICCs (>0.92).

4. Discussion

The main objective of the current study was to analyze the reliability of the new RunScribe™ system, based on three IMUs, to evaluate the kinematics of the pelvis during human locomotion. As shown in the results presented above, although the comparison of means between blocks did not report significant differences and the magnitude of these differences was trivial-small in most of the variables and conditions tested, the CVs obtained are, mostly, unacceptable from a practical standpoint. Only two (i.e., angular rate in the obliquity of the pelvis and the vertical oscillation) out of ten variables analyzed about the kinematics of the pelvis are reliable (with CV close to 10% in the different conditions). The rest of the variables present higher CVs, which imply a huge bias in the quality of the measure.

The validity and reliability of the RunScribe™ spatio-temporal parameters have been already analyzed [2], [4], [6]. García-Pinillos et al. [4] showed a high degree of agreement with a high-speed video analysis during treadmill running. Similarly, Hollis et al. [6] reported that Runscribe™ is a valid system to determine variations in spatio-temporal, kinetic and kinematic parameters on different surfaces and at different running speeds. On the other hand, Cartón-Llorente et al. [2] analyzed the reliability and absolute concordance between the Stryd (Stryd power meter, Stryd Inc., Boulder, CO, USA) and RunScribe™ systems for the evaluation of running power, observing a high reliability for both systems and a high degree of agreement between both. However, despite this evidence, no previous study has analyzed the reliability of the RunScribe™ system based on 3 IMUs and the metrics it provides regarding the biomechanics of the pelvis.

Regarding García-Pinillos et al. [4], the authors used a treadmill running protocol, setting an initial speed of 8 km/h, which was subsequently increased by 1 km/h every minute, until reaching a speed at which the participants felt comfortable. Once the accommodation interval was over, they began the registration period, which lasted 3 minutes at the same speed. In our case, unlike this study, we used a protocol with 3 different speeds (i.e., 5, 10 and 15 km/h) and the recordings were made in the last 20 seconds of each bout, where the subject had been already adapted to the running speed. On the other hand, it should be noted that these authors' registers came only from two footpods (one for each shoe) as the new update of the system had not been carried out yet.

Hollis et al. [6] carried out their protocols on different surfaces, particularly on tracks and grass. Although their study was completed outdoors, the authors placed the foot pods on the heel of the shoes, which might be a source of discrepancies in certain variables [4]. Further research is needed to determine the reliability and validity of the RunScribe system with 3 IMUs on different surfaces and settings.

It is noteworthy that the pelvic metrics provided by the RunScribe™ platform (i.e., anteversion, retroversion, obliquity, rotation and maximum angular rate) are based on the maximum and minimum values for each kinematic variable. Therefore, the operational range of the accelerometer might be the main cause of error [15]. Variables such as pelvic tilt are accentuated in running requiring, thus, a greater operational range of the accelerometer in order to keep the acceleration peaks produced. This fact might justify the reduction of the reliability of the device in running compared to waking in the metric of minimum (5 km/h: 12.8%; 10 km/h: 85.6%; 15 km/h: 77.2%) and maximum incline (5 km/h: 19.1%); 10 km/h: 95.8%; 15 km/h: 47.8%). Other sources of error that could justify the low reliability of the device is the fixation of the device on the waist of the shorts compared to the use of sports tights.

Finally, there are some limitations to be taken into account when interpreting the results obtained. The reliability of the RunScribe ™ system has been analyzed but its validity with respect to a reference system remains unknown. Then, the characteristics of the participants (i.e., physically active youth, but not highly specialized runners) should make the reader extremely cautious when extrapolating these results to other populations. Additionally, the conditions tested must be also considered as these findings might not be replicated when experimental conditions change (e.g., uphill or downhill running). Nevertheless, despite these limitations, the present study provides new knowledge of the data and the quality provided by a new wearable that is being massively used by both clinicians and sport practitioners given its user-friendliness.

5. Conclusions

The data obtained in the present study show that the RunScribe™ system, composed of 3 IMUs (footwear and sacrum), does not provide reliable metrics on the kinematics of the pelvis during human locomotion (i.e., gait and running).

Practical applications

From a practical standpoint, clinicians and sport practitioners must be aware of the limitations of the RunScribe™ system for evaluating pelvic kinematic during human locomotion. Its affordability and user-friendly character compared to more reliable technologies (e.g., 3D motion capture systems) might be a strong claim for users but the low reliability reported may jeopardize its utility in both sport and clinical settings.

Declarations

Competing interests

None.

Authors' contributions

All authors were involved in the design, data collection and manuscript preparation.

Data availability statement

Not applicable.

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