TITLE: Absolute reliability and concurrent validity of the Stryd™ system for the assessment of running stride kinematics at different velocities

RUNNING TITLE: Stryd™ system and running stride kinematics

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Key words: biomechanics; reliability; running; technology; validity

Abstract

This study aimed to determine the absolute reliability and to evaluate the concurrent validity of the Stryd™ system for measuring spatio-temporal variables during running at different velocities (8-20 km.h^{-1}) by comparing data with another widely-used device (the OptoGait™ system). Eighteen trained male endurance runners performed an incremental running test (8-20 km. h^{-1} with 3 min stages) on a treadmill. Spatio-temporal parameters (contact time [CT], flight time [FT], step length [SL], and step frequency [SF]) were measured using two different devices (Stryd™ and OptoGait™ systems). The Stryd™ system showed a CV <3%, except for FT (3.7-11.6%). The OptoGait™ achieved CV <4%, except for FT (6.0-30.6%). Pearson correlation analysis showed large correlations for CT and FT, and almost perfect for SL and SF over the entire protocol. The intra class correlation coefficients partially support those results. Paired t-tests showed that CT was underestimated ($p<0.05$, ES>0.7; ~4-8%), FT overestimated ($p<0.05$, ES>0.7; ~7-65%), while SL and SF were very similar between systems (ES<0.1, with differences <1%). The Stryd™ is a practical portable device that is reliable for measuring CT, FT, SL, and SF during running. It provides accurate SL and SF measures but underestimates CT (0.5-8%) and overestimates FT (3-67%) compared to a photocell-based system.

Key words: biomechanics; reliability; running; technology; validity

Word count: 2,829

Introduction

Interest in running gait analysis is appropriate in both an injury prevention (11,17) and an athletic performance context (1,3,13,18). 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. This has allowed researchers to remove participants from an artificial laboratory environment and measure participants in a more natural environment (14).

In the current study the authors compared Stryd™ data with a widely-used device for assessing spatio-temporal variables during locomotion. The OptoGait™ system is composed of photoelectric cells positioned along transmitting receiving bars of 1 m in length with a maximum distance of 6 m between bars. The transmitting-receiving bars contain infrared LED diodes, enabling communication between the two bars. When a subject passes between the transmitting bar and the receiving bar, the system automatically calculates spatio-temporal parameters by sensing interruptions in communication. The assessment results of this gait analysis system have been previously validated in healthy adults walking at a comfortable speed (9) and the system has been used to examine spatio-temporal parameters of athletes when running at different velocities and under different conditions (12,16).

Stryd system™ (www.stryd.com) is a pioneer in manufacturing wearable power meters for running. Power meters have helped performance-focused cyclists revolutionize their training and racing (15), and the same may soon be accomplished for runners. This power meter for runners is a foot pod that attaches to a running shoe to measure twelve metrics to quantify performance: pace, distance, elevation, running power, form power, cadence, ground contact time, vertical oscillation, leg stiffness. This is a relatively new tool, and there is not yet data to demonstrate validity and reliability of this device, making this type of study beneficial.

The variety of available technologies for gait analysis (e.g., accelerometers, gyroscopes, force plates, pressure plates, and photoelectric cells) implies a variety of devices should exist for analyzing stride characteristics. However, some of these devices have not yet been validated. The validity and reliability of a gait analysis system are essential to determine whether results are due to changes in gait pattern or are simply systematic measurement errors. Therefore, the aim of the current study is to determine the absolute reliability (within-subject variation) and to evaluate the concurrent validity of the Stryd™ system for measuring spatio-temporal variables during running at different velocities (usual for endurance runners at training and competing, 8-20 km.h^{-1}) by comparing data with a widely-used device for this purpose (i.e., the OptoGait™ system).

Methods

Experimental approach to the problem

With the introduction of new wireless devices, establishment of their reliability and validity are essential before practical use. In this study, the Stryd™ system was compared to the OptoGait™ system for measuring spatio-temporal variables during running at different velocities (8-20 km.h^{-1}).

Participants

A group of eighteen recreationally trained male endurance runners (age range: 19-46 years; age: 34±7 years; height: 1.76±0.05 m; body mass: 70.5±6.2 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 40 minutes, (3) training on a treadmill at least once per week, (4) not suffering from any injury (points 3 and 4 related to the last 6 months before the data collection). After receiving detailed information on the objectives and procedures of the study, each subject 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 if they saw fit. The study was approved by the Ethics Committee of the San Jorge University (Zaragoza, Spain).

Procedures

The study was conducted in June 2017. At the time of these observations, the subjects had completed between 6-7 months of training. Subjects were individually tested on one day (between 16:00 and 21:00 h). Prior to all testing, subjects refrained from severe physical activity for at least 48 h and all testing was at least 3 h after eating. Tests were performed with the subjects' usual training shoes to measure their typical performance.

Subjects performed an incremental running test on a motorized treadmill (HP cosmos Pulsar 4P, HP cosmos Sports & Medical, Gmbh, Germany). The initial speed was set at 8km.h^{-1}, and speed increased by 1 km.h^{-1} every 3 min until running speed reached 20 km.h^{-1}. The slope was maintained at 1% (0.9º). The treadmill protocol was preceded by a standardized 10-min accommodation programme (5 min walking at 5 km.h^{-1}, and 5 min running at 10 km.h^{-1}). Athletes were experienced in running on a treadmill.

Materials and testing

i) Anthropometry. For descriptive purposes, height (cm) and body mass (kg) were measured.

ii) Biomechanics. Spatio-temporal parameters were measured using two different devices:

- The OptoGait™ system (Optogait; Microgate, Bolzano, Italy) was previously validated for the assessment of spatio-temporal parameters of the gait of young adults (9). As indicated by Lee et al. (9), the OptoGait™ achieved a high level of correlation with all spatio-temporal parameters by intra-class correlation coefficients (0.785–0.952), coefficients of variation (1.66–4.06%), standard error of measurement (2.17–5.96%), and minimum detectable change (6.01–16.52%). The system detects any interruptions and therefore 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. Contact time (CT), flight time (FT), step length (SL), and step frequency (SF or cadence) were measured for every step during the treadmill test, and were defined as follows:
    - CT (s): time from when the foot contacts the ground to when the toes lift off the ground.
    - FT (s): time from toe-off to initial ground contact of consecutive footfalls (e.g., right-left).
    - SL (m): length the treadmill belt moves from toe-off to initial ground contact in successive steps.

    - SF or cadence (steps/min): number of ground contact events per minute.
- Stryd™ (Stryd Powermeter, Stryd Inc. Boulder CO, USA): a relatively new device which estimates power in watts. Stryd™ is carbon fibre-reinforced foot pod (attached to your shoe) that weights 9.1 grams. Based on a 6-axis inertial motion sensor (3-axis gyroscope, 3-axis accelerometer), this device provides spatio-temporal data including CT and SF. From CT and SF, in addition to running velocity, the authors calculated FT and SL as follows:

$$(1) \qquad FT\ (s) = step\ time\ (s) - CT\ (s),$$

where step time is the time from the beginning of the step cycle (take-off) to the end (previous frame to take-off),

$$step\ time\ (s) = 60\ /\ SF\ (steps/min)$$

$$(2) \qquad SL\ (m) = running\ velocity\ (m.min^{-1})\ /\ SF\ (steps/min)$$

Statistical analysis

Descriptive statistics are represented as mean (SD). Tests of normal distribution and homogeneity (Shapiro-Wilk and Levene's test, respectively) were conducted on all data before analysis. Coefficient of variation (CV, %) and standard error of the mean (SEM) were calculated as a measure of absolute reliability (within-subject variation and standard deviation of a sampling distribution, respectively) (2,6). Intra class correlation coefficients were calculated between OptoGait™ and Stryd™ data for each spatio-temporal variable analysed (CT, FT, SL, and SF). Values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability (8). To determine concurrent validity, a Pearson correlation analysis was also performed between OptoGait™ and Stryd™ data. 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) (7). Pairwise comparisons of means (t-test) were also conducted between data (CT, FT, SL, and SF) from the two devices (OptoGait™ and Stryd™) at different running speeds (8-20 $km.h^{-1}$). Additionally, the magnitude of the differences between values were also interpreted using the Cohen´s d effect size (ES) (19). Effect sizes of less than 0.4 represented a small magnitude of change while 0.41–0.7 and greater than 0.7 represented moderate and large magnitudes of change, respectively (19). The level of significance used was $p<0.05$. Data analysis was performed using SPSS (version 21, SPSS Inc., Chicago, Ill).

Results

Reliability

Table 1 shows the CV (as a measure of absolute reliability) of spatio-temporal parameters at different running velocities from both Stryd™ and OptoGait™. For the Stryd™ system, CV ranged between 1.2-2.3% (CT), 3.7-11.6% (FT), 1.1-2.1% (SL) and 1.1-2.0% (SF); whereas for the OptoGait™ system, CV was 2.3-3.0% (CT), 6.0-30.6% (FT), 2.0-3.8% (SL) and 2.2-3.6% (SF). Additionally, the SEM is provided in Table 2.

TABLE 1 ABOUT HERE

TABLE 2 ABOUT HERE

Validity

The Pearson correlation analysis is shown in Table 3 (CT, FT, SL, and SF or cadence at 8-20 $km.h^{-1}$ running velocities). CT from both devices showed large correlations (0.5-0.7,

$p<0.05$) at low speeds (8-11 km.h^{-1}) and race speeds (14-16 km.h^{-1}). FT from OptoGait™ and Stryd™ showed large and very large correlations, respectively ($0.602 < r > 0.834$, $p<0.05$) over the velocities tested (8-20 km.h^{-1}). SL and SF from both devices were nearly perfectly correlated ($r > 0.9$, $p<0.001$) at every running velocity tested.

TABLE 3 ABOUT HERE

The ICCs between kinematic variables from both Stryd vs. OptoGait systems over the entire protocol (8-20 km.h^{-1}) are included in Table 4. CT showed a low coefficient (<0.5), FT a moderate coefficient (0.5-0.75), whereas SL and SF showed excellent coefficients (>0.9).

TABLE 4 ABOUT HERE

A paired t-test demonstrated some significant differences ($p<0.05$) and large ES (>0.7) in the variables analysed (CT, FT, SL, and cadence) (Figures 1-4, respectively). CT (Figure 1) was underestimated for Stryd™ compared to OptoGait™ data (8-18 km.h^{-1}, $p<0.001$ and ES>0.7; ~6-8%). Differences were smaller at 19 km.h^{-1} ($p<0.05$ and ES>0.7; ~4%) and no differences were observed at 20 km.h^{-1} ($p\geq0.05$ and ES<0.1; ~0.5%).

FIGURE 1 ABOUT HERE

FT (Figure 2) was overestimated for Stryd™ based on OptoGait™ data at running velocities between 8-19 km.h^{-1} ($p<0.05$, ES>0.7; from ~65% at 8 km.h^{-1} to ~7% at 19 km.h^{-1}). No significant differences were found at 20 km.h^{-1} ($p\geq0.05$ and ES=0.57; ~3%).

FIGURE 2 ABOUT HERE

SL from both devices is shown in Figure 3. P-values show significant differences ($p<0.05$) between data from Stryd™ and OptoGait™ at most analysed velocities, although Cohen´s d showed a very small magnitude of changes (ES<0.1), with Stryd™ data overestimated compared to OptoGait™ data (<1%). Likewise, significant differences ($p<0.05$) were found in cadence between the two devices (Figure 4) but Cohen´s d reported a very small change (ES<0.1) with differences smaller than 1%.

FIGURES 3 AND 4 ABOUT HERE

Discussion

This study aimed to determine the absolute reliability and to evaluate the concurrent validity of the Stryd™ system for measuring spatio-temporal variables during running at different velocities (8-20 km.h^{-1}) by comparing data with a device widely-used for this purpose (OptoGait system™). The major findings of this study were: (i) CV, as a measure of reliability, was lower in all analysed variables for the Stryd™ system than for the OptoGait™ system (<5% in all cases, except for FT), while SEM was almost identical for every variable over the entire protocol (8-20 km.h^{-1}); (ii) concurrent validity of the Stryd™ and OptoGait™ systems regarding spatio-temporal variables is not yet settled: moderate for CT, low for FT, and very high for SL and SF. Results from Pearson correlation analysis indicated a strong concurrent validity over the entire range of running velocities (8-20 km.h^{-1}), with large correlations in CT, very large correlations in FT and almost perfect correlations in SL and SF. The ICCs partially provide support to those results with excellent coefficients for SL and SF and moderate for FT, but poor coefficients for CT (over the entire protocol). Additionally, the paired t-test let us improve our comparison and some interesting findings are worth noting: (i) The Stryd™ system underestimated CT (up to ~8% at low velocities) and overestimated FT (up to ~65% at low velocities) compared with the OptoGait system™, with reduced differences at high running velocities; (ii) despite differences in p-values, the very small magnitude of changes reported suggests that SL and SF (from the Stryd™ system) are valid variables over running velocities of 8-20 $km.h^{-1}$, compared with the OptoGait™ system.

As mentioned earlier, scientists have discovered the potential of accelerometers (and inertial measurement units, IMUs) in assessing gait analysis without the restrictions of laboratory technology. Having the chance to measure athletes or clients in a natural environment and using less expensive and more time-efficient equipment is a huge step forward for coaches and clinicians. Nevertheless, this advantage would be worthless if the data were not valid. The Stryd™ system (based on a 6-axis inertial motion sensor: 3-axis gyroscope, 3-axis accelerometer) is mainly a running power meter, but it also provides spatio-temporal variables that are used by coaches and clinicians (information easily accessible to users) as a feedback, necessitating confirmation of the validity of these data.

Comparing between devices and technologies (i.e., photoelectric cells vs. IMUs), the authors hypothesize that differences in temporal variables might be at least partially explained by the height of the OptoGait system™´s LED diodes. As described by Lienhard et al. (10), the LED diodes of the OptoGait™ system are positioned 3 mm above ground and thereby, sensing of heel contact occurs earlier, whereas sensing of toe lift-off occurs later in the gait cycle (timing differences). In a similar previously published study (4), the authors assessed the reliability and validity of an accelerometer-based system (Myotest®) against a photocell-based system (OptoJump™) for measuring running stride kinematics.

In line with our data, the authors reported CT 34% shorter and FT 64% longer than the photocell-based system. That work (4) also found a good validity in SF. Therefore, the data obtained in the current study agree with those reported by previous studies that compared accelerometer-based systems to photocell-based systems, and our results support the explanation for this discrepancy given by Lienhard et al. (10).

Some final limitations need to be taken into consideration. First, the use of photocell-based systems as the gold standard reference for establishing concurrent validity should be evaluated, instead of instruments that measure ground reaction force, such as a force platform. Because we do not possess such equipment in our laboratory, the use of the OptoGait system was considered to be an adequate proxy system given its demonstrated good validity compared to GAITRite system® –pressure platform- (9) or compared to force platform during jumping tests (5). Furthermore, the OptoGait system™ is more practical and portable for recording several consecutive steps than force or pressure platforms imbedded into the ground in series where participants often have to adjust SL and target platforms to obtain clearly defined foot contact data. A second consideration is that validation data were obtained from an analysis based on within-subject variation (CV) rather than on different days. Although the number of steps analysed in 3-min of running at these velocities is high (400-500 steps in 3 min), our current reliability statistics might not generalise to runs performed several days apart.

Conclusion

To sum up, based on traditional thresholds, the absolute (i.e., CV) reliability of CT, FT, SL, and SF derived using the Stryd™ device were classified as adequate for running assessments, and this suggests that the Stryd™ is useful for monitoring individuals and quantifying changes in functional performance over time. However, the concurrent validity of Stryd™ as compared to OptoGait™ was low-moderate for CT and FT, and excellent for SL and SF. The paired comparisons added to those correlations showed that the Stryd™ system underestimated CT (0.5-8%) and overestimated FT (3-67%) compared with OptoGait™ system, with reduced differences at elevated running velocities (8-20 km.h^{-1}). On the other hand, SL and SF were valid variables (<1%) over the entire range of running velocities, as compared with the OptoGait™ system.

Practical applications

From a practical point of view and considering that both systems are widely used, scientists and clinicians should know that both devices showed an adequate reliability for running assessments and, thereby, spatio-temporal parameters reported from these devices can be compared over time (if using the same device). However, the clients also should be aware about the limitations of comparing data reported from these two devices.

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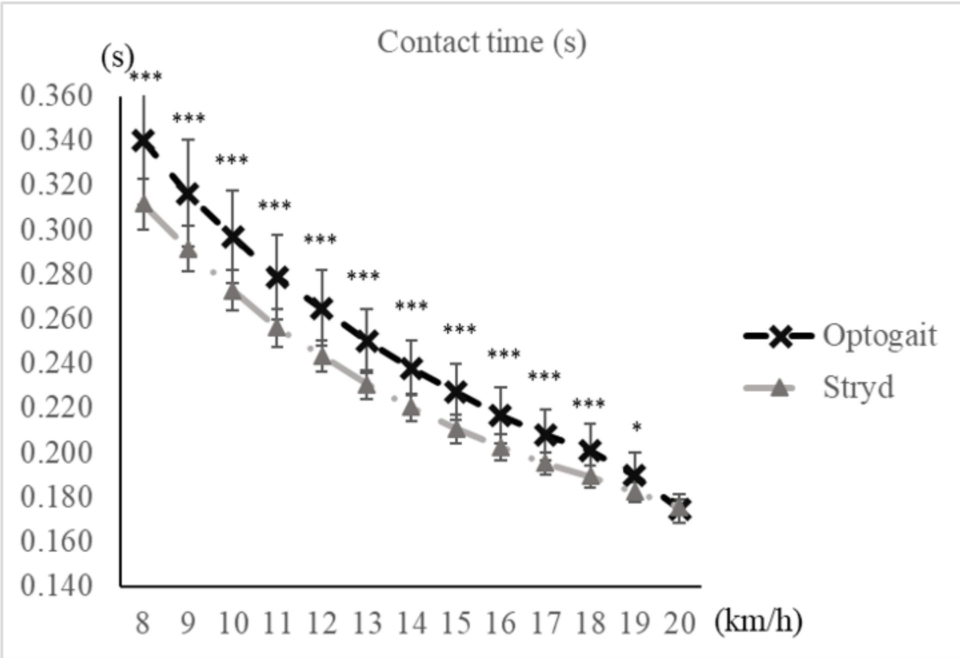

Figure 1. Contact time (s) during running measured by Stryd™ and OptoGait™ systems.

*p<0.05, **p<0.01, ***p<0.01

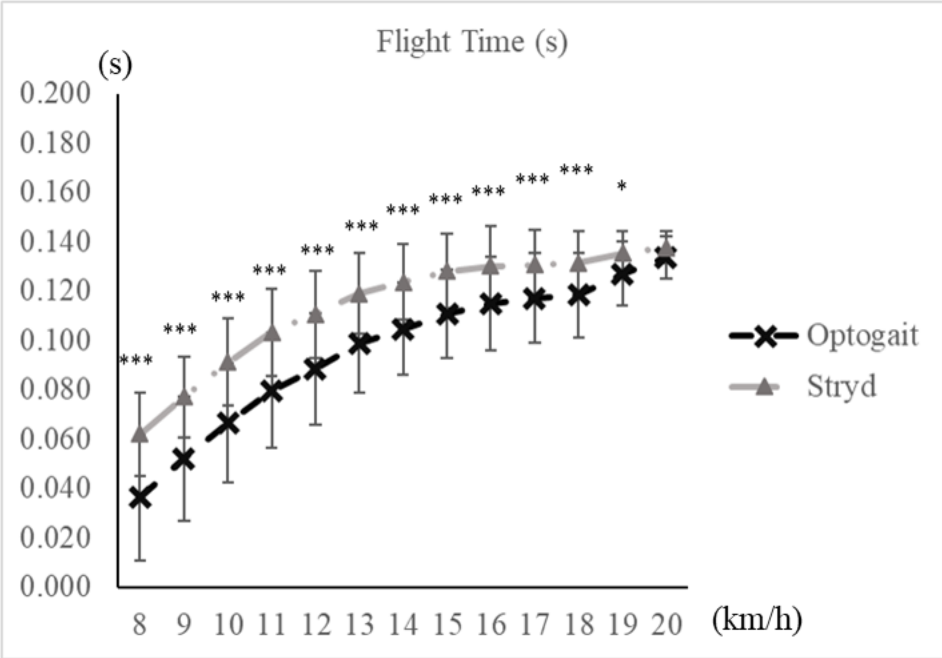

Figure 2. Flight time (s) during running masured by Stryd™ and OptoGait™ systems.

*p<0.05, **p<0.01, ***p<0.01

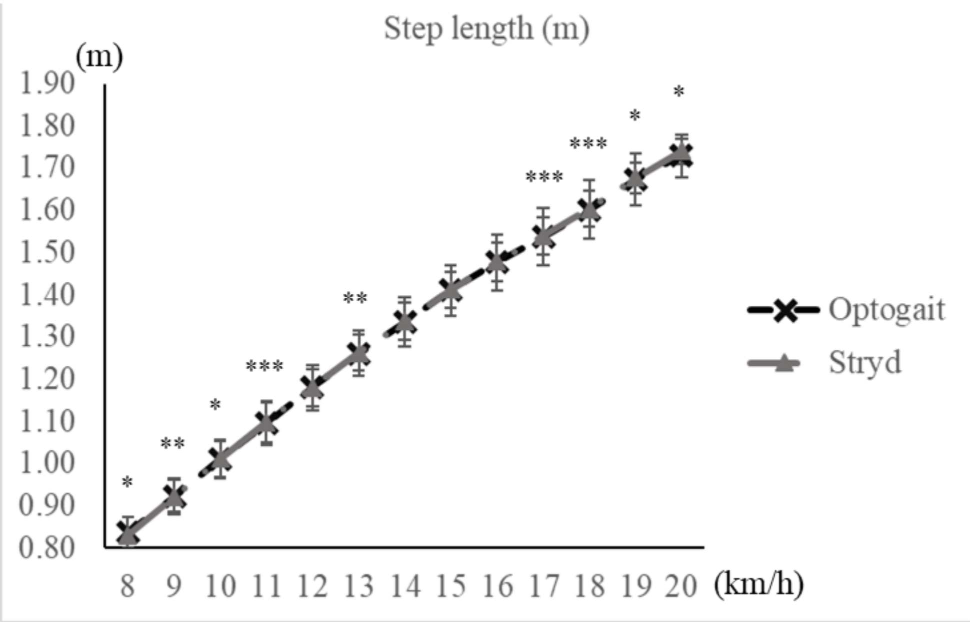

Figure 3. Step length (cm) during running measured by Stryd™ and OptoGait™ systems.

*p<0.05, **p<0.01, ***p<0.01

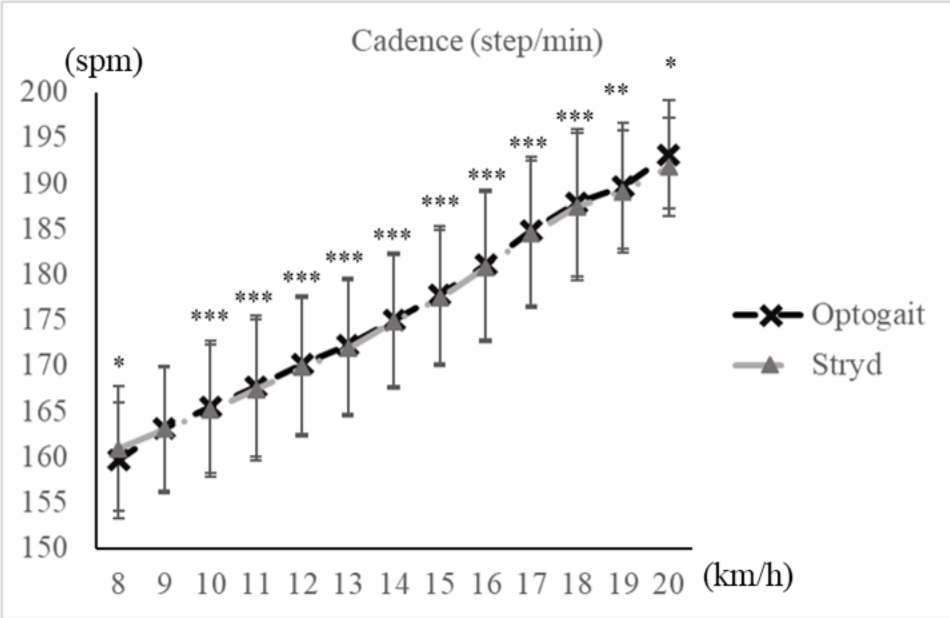

Figure 4. Step frequency (cadence, step/min) during running measured by Stryd™ and OptoGait™ systems. *$p<0.05$, **$p<0.01$, ***$p<0.01$

Table 1. Coefficient of variation (%) of the spatio-temporal parameters (CT, FT, SL and SF) at different running velocities (8-20 $km.h^{-1}$) from OptoGait system and from Stryd system.

Speed	Contact time (CT)		Flight time (FT)		Step length (SL)		Step frequency (SF)	
($km.h^{-1}$)	Stryd	OptoGait	Stryd	OptoGait	Stryd	OptoGait	Stryd	OptoGait
8	1.46	3.01	11.60	30.58	1.32	3.78	1.31	3.13
9	1.38	2.91	9.38	24.17	1.38	3.61	1.33	3.30
10	1.53	2.90	7.35	18.62	1.22	3.39	1.19	3.14
11	1.43	2.79	5.78	14.01	1.13	3.28	1.11	3.06
12	1.37	2.59	5.21	11.44	1.24	3.04	1.19	2.77
13	1.22	2.56	4.27	9.05	1.09	2.74	1.05	2.79
14	1.27	2.48	4.18	8.26	1.14	2.63	1.13	2.52
15	1.34	2.41	4.29	7.05	1.33	2.24	1.26	2.35
16	1.91	2.53	4.59	6.46	1.20	1.98	1.17	2.33
17	1.56	2.38	3.73	6.38	1.32	2.02	1.29	2.30
18	1.98	2.33	5.11	6.37	1.86	2.08	1.69	2.15
19	2.23	2.45	5.39	6.41	2.02	2.24	1.87	2.27
20	2.32	2.48	7.56	6.01	2.08	2.66	2.01	3.54

Table 2. Standard error of mean (SEM) of the spatio-temporal parameters (CT, FT, SL and SF) at different running velocities (8-20 $km.h^{-1}$) from OptoGait system and from Stryd system.

Speed	Contact time (CT)		Flight time (FT)		Step length (SL)		Step frequency (SF)	
($km.h^{-1}$)	Stryd	OptoGait	Stryd	OptoGait	Stryd	OptoGait	Stryd	OptoGait
8	0.005	0.005	0.008	0.009	1.345	1.259	2.483	2.269
9	0.004	0.005	0.007	0.009	1.228	1.179	2.138	2.068
10	0.003	0.004	0.005	0.007	1.071	1.032	1.746	1.777
11	0.003	0.003	0.005	0.007	1.479	1.539	2.213	2.234
12	0.003	0.003	0.005	0.007	1.572	1.539	2.227	2.229
13	0.003	0.002	0.004	0.005	1.583	1.497	2.108	2.103
14	0.003	0.002	0.004	0.005	1.704	1.757	2.198	2.179
15	0.002	0.002	0.003	0.004	1.794	1.730	2.207	2.164
16	0.002	0.002	0.003	0.004	1.930	1.881	2.318	2.355
17	0.002	0.002	0.003	0.004	2.146	2.151	2.507	2.529
18	0.001	0.002	0.004	0.004	2.412	2.484	2.771	2.787
19	0.001	0.002	0.003	0.003	2.252	2.278	2.535	2.591
20	0.001	0.003	0.003	0.003	2.013	2.079	2.211	2.406

Table 3. Pearson correlation between kinematics variables from Stryd vs. Optogait over an incremental running test (8-20 km.h^{-1}).

Speed (km.h^{-1})	8	9	10	11	12	13	14	15	16	17	18	19	20
Contact time	0.657**	0.636**	0.574*	0.525*	0.433	0.435	0.507*	0.504*	0.503*	0.453	0.415	0.429	0.078
Flight time	0.602**	0.656**	0.685**	0.703**	0.722**	0.739***	0.722***	0.782***	0.811***	0.800***	0.775***	0.680*	0.834*
Step length	0.934***	0.999***	0.999***	0.999***	0.999***	0.998***	0.997***	0.998***	0.999***	0.999***	0.999***	0.997***	0.991***
Step frequency	0.959***	0.996***	0.999***	0.999***	0.999***	0.999***	0.999***	0.999***	0.999***	0.999***	0.999***	0.999***	0.999***

* p<0.05; ** p<0.01; *** p<0.001

Table 4. Intra class correlation coefficients (ICC) between kinematics variables from Stryd vs. Optogait over an incremental running test (8-20 km.h^{-1}).

Speed (km.h^{-1})	8	9	10	11	12	13	14	15	16	17	18	19	20
Contact time	0.457	0.463	0.416	0.386	0.303	0.330	0.407	0.400	0.380	0.329	0.294	0.381	0.063
Flight time	0.555	0.599	0.655	0.679	0.702	0.726	0.758	0.768	0.799	0.778	0.744	0.635	0.806
Step length	0.934	0.998	0.999	0.999	0.999	0.998	0.997	0.998	0.999	0.999	0.999	0.997	0.991
Step frequency	0.956	0.995	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.997	0.983