Validity and Reliability of the 3D Motion Analyzer in Comparison with the Vicon Device for Biomechanical Pedalling Analysis

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Abstract: The present work aimed to assess the validity and reliability of the 3D motion analyzer (Shimano Dynamics Lab, Sittard, Netherland) during laboratory cycling tests in comparison with the Vicon device (Vicon Motion Systems Ltd. Oxford, UK). Three cyclists were required to complete one laboratory cycling test at three different pedalling cadence and at a constant power output. Kinematic measurements were collected simultaneously from 3D motion analyzer and Vicon devices and performed five times for each pedalling cadence. The two systems showed a high reliability with excellent intraclass correlation coefficients for most kinematic variables. Moreover, this system was considered as valid by considering the error due to the initial markers placement. Experts and scientists should use the Vicon system for the purpose of research whereas the 3D motion analyzer could be used for bike fitting.

1 INTRODUCTION

Bike fitting is an important process to adjust the geometry of the bike and its components to the needs of the cyclist. Optimal position on the bicycle may be considered as a position in which force application and comfort are maximised, whilst resistive forces and risk of injury are minimised, in order to maximise bicycle velocity (Iriberri et al., 2008). The manipulation of a single variable such as saddle height can improve performance within cycling economy (Peveler and Green, 2010) and power output in anaerobic exercises (Peveler et al., 2007).

Numerous methodologies and systems have been proposed to perform bike fitting (Holmes et al., 1994, Iriberri et al., 2008, Nordeen-Snyder, 1977). However, different kinematic systems do not necessary provide the same results (Fonda et al., 2014). Umberger and Martin (Umberger and Martin, 2001) reported that no significant difference exist between 3D and 2D kinematic systems whereas Fonda *et al.* (Fonda et al., 2014) measured significant differences between the two systems. The 3D motion analyzer (Shimano Dynamics Lab, Sittard, Netherland) is a new kinematic system positioned in the sagittal plane and tracking LED markers attached to the skin.

This study aimed to assess the validity and reliability of the 3D motion analyzer in comparison with the Vicon device for biomechanical pedalling analysis. We hypothesized that 1) the kinematic variables measured by the two systems would be similar and 2) the two systems will achieve an excellent reliability.

2 METHODS

Three cyclists volunteered to participate in the study. Prior to testing and after having received a full explanation of the nature and purpose of the study, the participants gave their written informed consents. The participants performed one testing session with the same road-racing bicycle (Lapierre Pulsium, Dijon, France). The validity and reliability

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of the 3D motion analyzer was investigated on an Elite Novo Force home-trainer (Elite, Fontaniva, Italy) (figure 1) at three different pedalling cadences (60, 90 and 120 rpm) and at a constant power output (200 W) measured by a SRM power meter (SRM, Schoberer Rad Messtechnich, Julich, Germany). Kinematic measurements were performed five times for each pedalling cadence resulting in 15 different data sets by participant, each data set lasting 10 seconds.

Kinematic analysis of the cyclists' right side was performed assuming symmetry of motion between left and right sides (Heil et al., 1997, Garcia-Lopez et al., 2015) and using the 3D motion analyzer. Height LED markers with built-in probe were attached to the skin of the cyclists (fifth metatarsal head, calcaneus, lateral malleolus, lateral femoral epicondyle, greater trochanter, acromion, lateral epicondyle of the humerus and styloid process of the ulna) (Bini et al., 2010a, Ferrer-Roca et al., 2012). The 3D sensor was positioned 2 m away from the sagittal plane and was calibrated before the study as recommended by the manufacturer. Automatic tracking, processing and analysing data were performed by a specific software (Bikefitting.com, Version 2.1.5, Shimano Dynamics Lab, Sittard, Netherland).

Kinematic data were also collected from 12 passive markers recorded by twelve infrared cameras (Vicon Motion Systems Ltd. Oxford, UK). These markers were attached in the same line, interspersed within active ones (LED markers). The Vicon system (using Nexus 1.7.1 software) is a marker-based motion capture system acknowledged as a reference. This motion capture system carries 12 MX3+ cameras with a frequency of 200 Hz, a millimeter accuracy and a resolution of 659 × 494 pixels each. The data processing was performed using custom-made code written in Matlab software (Matlab Release 2014a, The MathWorks, Inc., Natick, Massachusetts, USA).

Shoulder, forearm, elbow, torso, hip, knee, ankle and foot (vertical and lateral) angles were determined. Angular position values of the hip, knee and ankle were expressed as flexion (minimum angle) and extension (maximum angle). Knee lateral travel and knee travel tilt were also measured during the study.

3 RESULTS AND DISCUSSION

The two devices showed a high reliability with no significant difference and excellent intraclass correlation coefficients (Cicchetti, 1994) for most kinematic variables (table 1). This results confirmed our hypothesis showing that the two systems achieved a high reliability.

Table 1: Intraclass correlation coefficients (ICC) for the two systems and for all kinematic variables.

Variable	***ICC***	
	Vicon	***Motion Analyzer***
Shoulder angle (°)	0.90	0.93
Forearm angle (°)	0.35	0.63
Elbow angle (°)	0.74	0.59
Torso angle (°)	0.79	0.95
Hip angle extension (°)	0.86	0.63
Hip angle flexion (°)	0.94	0.97
Knee angle extension (°)	0.96	0.98
Knee angle flexion (°)	0.88	0.97
Knee lateral travel (mm)	0.84	0.88
Knee travel tilt (°)	0.99	0.92
Foot vertical angle (°)	0.89	0.66
Foot lateral angle (°)	0.97	0.94
Ankle angle maximum (°)	0.97	0.92
Ankle angle minimum (°)	0.84	0.89
Ankle range (°)	0.85	0.72

Figure 1: settings for the experiment.

All kinematic variables collected with the 3D motion analyzer were significantly correlated with those collected with the Vicon device (table 2) except for knee angle flexion and foot lateral angle. However, some statistical differences have been reported suggesting that the 3D motion analyzer measurements were significantly different that those measured with the Vicon system. The present study

Table 2: Comparative statistics of kinematic variables (n = 3) measured during the session between the Vicon system and the 3D motion analyzer system for all pedalling cadences. Values are reported as mean ± SD.

Variable	*Vicon*	*Motion Analyzer*	*Statistical difference*	*Linear regression (R^2)*	*Bias*	*95% CI-*	*95% CI+*
Shoulder angle (°)	*77.7 ± 4.5*	74.9 ± 4.0	**	0.96**	-2.8	-4.7	-0.9
Forearm angle (°)	*41.3 ± 2.1*	39.7 ± 2.7	**	0.55**	-1.6	-5.1	1.9
Elbow angle (°)	*158.4 ± 4.8*	157.2 ± 3.4	*	0.66**	-1.2	-6.9	4.4
Torso angle (°)	*45.5 ± 2.5*	45.2 ± 3.3	n.s.	0.86**	-0.3	-3.0	2.4
Hip angle extension (°)	105.7 ± 4.7	104.6 ± 3.8	**	0.70**	-1.0	-6.1	4.0
Hip angle flexion (°)	59.1 ± 3.4	62.3 ± 1.2	n.s.	0.18*	3.2	-3.0	9.3
Knee angle extension (°)	40.2 ± 2.6	46.6 ± 5.0	**	0.76**	6.3	0.5	12.2
Knee angle flexion (°)	119.5 ± 2.1	114.7 ± 3.3	**	0.01	-4.8	-12.4	2.8
Knee lateral travel (mm)	18.3 ± 6.5	22.2 ± 9.2	**	0.66**	3.9	-6.7	14.5
Knee travel tilt (°)	3.8 ± 1.9	3.6 ± 2.5	n.s.	0.23**	-0.2	-7.8	7.3
Foot vertical angle (°)	26.6 ± 2.1	25.9 ± 2.9	*	0.39**	-0.7	-5.1	3.7
Foot lateral angle (°)	5.7 ± 1.8	8.3 ± 2.0	**	0.05	2.6	-2.0	7.2
Ankle angle maximum (°)	101.5 ± 6.3	99.3 ± 5.7	**	0.92**	-2.1	-5.7	1.4
Ankle angle minimum (°)	75.4 ± 3.5	75.6 ± 4.0	n.s.	0.87**	0.2	-2.6	3.0
Ankle range (°)	26.0 ± 4.2	23.6 ± 3.6	**	0.92**	-2.4	-4.9	0.1

* Significant at $p < 0.05$; ** Significant at $p < 0.001$; 95% CI = 95% Confidence Interval.

confirmed that various motion capturing systems do not necessarily provide the same results as they work on different basis (Fonda et al., 2014). This is of practical importance when adjusting body position. Even though most of the kinematic variables were significantly different, these differences are often less than 3°.

These results underlined the importance of the markers placement for comparative and statistical analysis between the two systems. Considering the error due to the initial markers placement (obtained for each cyclist) as an offset, we could compensate the significant difference obtained for knee angle extension (6.3°). To a lesser extent, the differences measured between the two systems could be influenced by some movements of the 3D motion analyzer markers (altering the alignment with the Vicon markers) during dynamic measurements. Our results indicated that with a cycling specific motion analysis tool and easy post-processing analysis, we are able to obtain reliable and useful data for bike fitting, in comparison with a full 3D motion capture system.

There was a significant increase in knee extension (from 38.4 to 42.3°) and knee flexion (from 118.5 to 120.6°) mean angles with increasing pedalling cadence only with the Vicon device. Additionally, foot vertical and ankle range mean angles were significantly increased with pedalling cadence for both the 3D motion analyzer and the Vicon system. Divergence among studies has been observed regarding the contribution of each joint (Hoshikawa et al., 2007, Mornieux et al., 2007, Bini et al., 2010b). The current study indicated that knee joint changed with increasing pedalling cadence whereas several authors (Bini et al., 2010b, Ericson, 1988) have reported no change. However, ankle range increased when pedalling cadence was increased from 60 to 120 rpm. This result is in accordance with previous studies (Ericson, 1988, Hoshikawa et al., 2007, Mornieux et al., 2007, Bini et al., 2010b) suggesting that ankle joint muscles control the pedal force application.

Note that this study is limited to only three participants and is therefore considered as preliminary. Nevertheless, the study design provided a large number of measurement over a variety of pedalling cadences typically generated by elite athletes.

4 CONCLUSIONS

The 3D motion analyzer showed a high reliability. Moreover, this system was considered as valid after compensation of the operator dependent error due to the initial markers alignment between the two systems.

Experts and scientists should use the Vicon system for the purpose of research whereas the 3D motion analyzer could be used for bike fitting. Bike fitting experts could employ a correction factor for each kinematic variables using the constant bias measured in our study. Additionally, these experts must standardize the pedalling cadence during bike fitting sessions considering that the contribution of the ankle joint was influenced by the pedalling cadence.

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