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Does the Retül System provide reliable kinematics information for cycling analysis?

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Abstract: The Retül Vantage system is a popular tool to assess dynamic positioning of cyclists. Despite its low sampling rate (18 Hz) to record position data, Retül measures shows a moderate to very high correlation with data from gold-standard tridimensional camera systems reaching higher sampling rates, but its reliability has not been tested. Here we assess the reliability of the Retül Vantage system for kinematic assessment of cyclists. This cross-sectional study had two phases. Phase 1 included a survey with certified Retül bike fitters to select the most common variables used in cycling kinematics assessment. Phase 2 involved assessment of the selected cycling kinematics variables to check for intra-examiner reliability. Ten bike fitters answered the online survey (response rate of 47.6%) and 7 variables were identified as the most common to conduct bike fitting analysis. Then, ten cyclists were submitted to kinematic assessments and Vantage system variables were checked for inter-examiner reliability and standard error of measurement. Good to excellent inter-tester reliability levels were found for all the 7 kinematics variables tested. Standard error was lower than 3º for all angular variables as well as lower than 5 mm for the linear variable tested. The minimal detectable difference values ranged from 2.15 to 6.55º for angular variables and of 15.51 mm for the linear variable. A high and very high degree of intra-rater reliability can be achieved using Retül Vantage system for kinematics assessment of the most common variables included in bike fitting.

Keywords: pedaling; bicycle; bike fit; bike fitting; angles; reliability

1. Introduction

Cycling is a popular sport worldwide and also a cause of injuries related to the practice like in other sports (van Mechelen, Hlobil, & Kemper, 1992). Traumatic injuries in cyclists can be prevented by wearing protective equipment, keeping the bicycle in good mechanical conditions, and adopting a safe riding behavior (Mellion, 1991; Dettori & Norvell., 2006), but overuse injuries are more complex and difficult to predict. Such injures can be reported by up to 62% of practioners in the case of mountain bike cycling (Lebec, Cook, & Baumgartel, 2014) and are often result from an incorrect interaction between the cyclist and the bicycle (Lebec et al., 2014;

Sabeti-Aschraf, 2014). Most of intervention and prevention strategies concerning overuse injuries in cyclists are based on optimizing body positioning on the bike in a procedure known as bike fitting (Bini & Carpes, 2014).

Bike fitting requires the quantification of body position. Numerous different methods can be implemented to perform bike fitting, ranging from static to dynamic procedures (Fonda, Sarabon, & Li, 2014). Along with the technology development over the last years, dynamic bike fitting methods have become popular. Most of the dynamic methods are based on 2D kinematic data, which are easier to implement in clinics and cycling clubs, as well as can be cheaper to implement than 3D assessments (Scoz et al., 2021). The Vantage system (Retül - Crucial Innovation, USA) was developed to assess dynamic positioning of cyclists and, despite of the limited sampling rate due to the use of a slow frequency infrared camera (18 Hz), it shows a moderate to very high degree of correlation with a gold-standard indoor laboratorial tridimensional camera system (i.e., Vicon). Thus, an acceptable level of accuracy for cycling kinematics analysis using this tool is suggested (FitzGibbon, Vicenzino, Rauh, Nichols, & Sisto, 2017; Scoz et al., 2021).

However, to the best of our knowledge, Vantage system have not been tested for reliability. A reliable measurement reflects the extent to which it is consistent and free from error. As such, data can be considered as accurate and meaningful if reliability, as the first prerequisite at the heart of measurement, is obtained (Portney, 2020). Therefore, in this study we assess the reliability of the Vantage system for analysis of cyclists' kinematics.

2. Materials and Methods

This cross-sectional study had two phases. Phase 1 included a survey with certified Retül bike fitters aiming to determine the common variables used in routines of cycling kinematics assessment. Phase 2 involved the assessment of intra-examiner reliability for the selected variables.

Bike fitters included in the phase 1 were recruited from a contact list of certified Retül fitters from Retül official website. Then, an informative e-mail with information about the research along with an invitation to participate in the study was sent to all the 21 Brazilian Retül certified bike fitters. Inclusion criteria was to use the Retül motion analysis system (Retül – Crucial Innovation, USA) for assessment of body positioning in cycling for at least 2 years. All participants agreeing to participate gave their informed consent in accordance with Declaration of Helsinki and approved by the committee of ethics in research from the local university. For those who agreed to participate, an on-line questionnaire with 10 multiple-choice questions was sent to identify which of Retül variables they usually included in the routines of kinematic assessment of cyclists. Variables reported for a frequency equal or higher than 70% were considered (Table 1).

In the phase 2, the most common variables for kinematics assessments were selected for assessment of intra-tester reliability and standard error. In this phase, amateur men and women athletes were recruited from a client mailing list from a sports physical therapy clinic. An informative e-mail about the research along with an invitation to participate in the study was sent. Participants should be older than 18 years old, without history of physical complaints, trauma or surgical procedure in the spine or in the upper and lower limbs in the last 12 months, no clinical diagnosed orthopedic and neurological disorders or pregnancy, and completing a total weekly training volume greater than 100 km (Priego Quesada, Kerr, Bertucci, & Carpes, 2018). Participants would be excluded if reporting any physical complaints while pedaling and 7 or less points of functional impact in the 0-10 Patient-Specific Functional Scale (PSFS) (Stratford, 1995; Wageck et al., 2013). A total of 10 cyclists (4 road cyclists and 6 mountain bike cyclists, Table 2) signed an informed consent form in accordance with Declaration of Helsinki approved by the committee of ethics in research from the local university and agreed to participate in the study. Participants had their characteristics assessed by the Cyclist Profile Questionnaire adapted from Fuller et al. (Fuller et al., 2006) and Clarsen et al (Clarsen, Krosshaug, & Bahr, 2010) to collect data on cyclists' demographic, anthropometric data, and training features, as well as Patient Specific Functional Scale (Stratford, 1995).

For kinematics data collection, participants were positioned on their own bicycle mounted on a stationary cycling trainer (CycleOps PowerBeam training roller, Saris Cycling Group, USA). While on the bicycle, Retül LED sensors, sampling data at 18 Hz, were placed directly on the cyclist's skin and fixed with adhesive tape. They cycled at cadence of ~90 revolutions per minute (rpm) with a resistance of 200 W (Bailey, Maillardet, & Messenger, 2003) for 3 minutes, which led to an average of 180 pedaling cycles recorded. Prior to inception of motion capture, a calibration procedure in accordance with Retül protocol that comprises the use of a crankarm block for the system properly find and set the pedal spindle was conducted. Motion capture was then performed considering data from the preferred leg to kick a ball. The first and the last 30 seconds of pedaling were excluded to avoid unusual body positioning and movement patterns due to acceleration and deceleration phases, respectively. The procedure was repeated twice with the same examiner assessing the participants in an interval of three days for intra-tester reliability analysis.

From Retül data, the mean angular measures during the 3-minute analysis period were determined from position data of markers placed over the anatomic references of the fifth metatarsophalangeal joint, lateral malleolus, lateral femoral condyle, greater trochanter, acromion, lateral humerus epicondyle and styloid process of ulna (Figure 1). Linear measures for the knee were calculated from the relative position of the lateral femoral condyle and the fifth metatarsophalangeal joint markers on the sagittal plane.

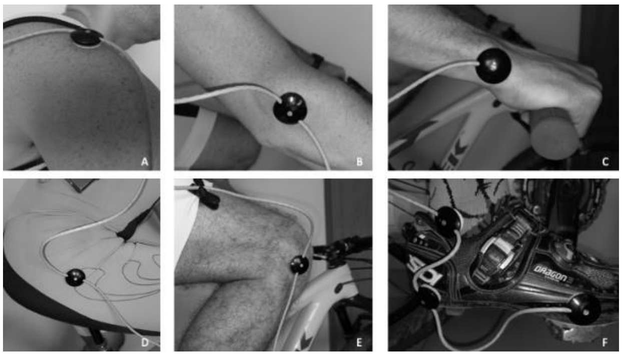

Figure 1. Retül system markers placement for data collection: A – acromion; B - lateral humerus epicondyle; C - styloid process of ulna; D - greater trochanter; E - lateral femoral condyle; F - fifth metatarsophalangeal joint and lateral malleolus.

Statistical analyses were performed using the SPSS® statistical package, version 19.0 (SPSS Inc., Chicago, IL, USA) and a customized Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) spreadsheet. Data normality was checked using Shapiro-Wilk test. Expert's responses frequencies and intraclass correlation coefficients ($ICC_{3,3}$) were used to select the Retül variables for the kinematics analyses and to determine intra-examiner reliability. In addition, the standard error of measurement (SEM) was calculated for each measure.

3. Results

Ten experts, with mean experience of 2.4 years using the system to assess cyclists agreed to participate in the survey and answered to the online questionnaire (response rate of 47.6%). From 37 available variables delivered by the Retül system, participants indicated 28 as usual applicable during their routines of bike fitting analysis. Analyses of their responses to the online questionnaire indicated 7 variables more frequent in the assessment of cyclists, defined as follows (Figure 2):

- AMAX - peak plantarflexion angle in the pedal stroke defined by the knee-ankle line and the heel-foot-line;

Table 1. Survey responses

RETÜL SYSTEM VARIABLES	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	TOTAL FREQUENCY	RELATIVE FREQUENCY
Ankle minimum (º)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	100%
Ankle maximum (º)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	9	90%
Ankle Range (º)	Y	N	Y	N	Y	N	N	Y	N	Y	6	60%
Ankle Angle at Top (º)	N	N	N	N	N	N	N	N	N	N	0	0%
Ankle Angle at Front (º)	N	N	N	N	N	N	N	N	N	N	0	0%
Ankle Angle at Bottom (º)	N	N	N	N	N	N	N	N	N	N	0	0%
Ankle Angle at Rear (º)	N	N	N	N	N	N	N	N	N	N	0	0%
Maximum Knee Flexion (º)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	100%
Maximum Knee Extension (º)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	100%
Knee Angle Range (º)	N	N	Y	N	Y	N	N	Y	N	Y	3	30%
Hip Angle Closed (º)	Y	Y	Y	N	N	Y	N	N	Y	Y	6	60%
Hip Angle Open (º)	Y	N	N	N	N	Y	N	N	N	N	2	20%
Hip Angle Range (º)	Y	N	N	N	N	Y	N	N	N	N	2	10%
Back Angle (º)	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	9	90%
Shoulder Angle to Wrist (º)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	100%
Shoulder Angle to Elbow (º)	N	Y	N	N	N	N	N	N	N	Y	2	20%
Elbow Angle (º)	N	N	N	N	Y	N	N	N	N	N	1	10%
Forearm Angle (º)	N	N	N	N	N	N	N	N	N	N	0	0%
Knee Forward of Foot (mm)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	9	90%
Knee Forward of Pedal Spindle (mm)	N	N	N	N	N	N	N	N	N	Y	1	10%
Knee to Foot Lateral Offset (mm) (mm)	N	N	N	N	N	Y	N	N	N	N	1	10%
Hip to Foot Lateral Offset (mm)	N	N	Y	N	N	Y	N	N	Y	N	3	30%
Shoulder to Wrist Lateral Offset (mm)	N	N	N	N	N	N	N	N	N	N	0	0%
Foot From Level Mean (º)	N	N	N	N	N	Y	N	N	N	N	1	10%
Foot Float Angle Min (º)	N	N	N	N	N	N	N	N	N	N	0	0%
Foot Float Angle Mean (º)	N	N	N	N	N	Y	N	N	N	N	1	10%
Foot Float Angle Max (º)	N	N	N	N	N	Y	N	N	N	N	1	10%
Knee Travel Tilt (º)	Y	Y	Y	N	N	N	Y	N	Y	Y	6	60%
Knee Lateral Travel (mm)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	100%
Hip Vertical Travel (mm)	Y	Y	N	N	Y	Y	N	N	N	Y	5	50%
Hip Lateral Travel (mm)	N	N	N	N	N	Y	N	N	N	N	1	10%
Thigh Length (mm)	Y	N	N	N	N	Y	Y	N	N	Y	4	40%
Shin Length (mm)	Y	N	N	N	N	Y	Y	N	N	Y	4	40%
Hip to Wrist Vertical (mm)	N	N	Y	N	N	N	N	N	N	N	1	10%
Hip to Wrist Horizontal (mm)	N	N	Y	N	N	N	N	N	N	N	1	10%
Hip to Elbow Vertical (mm)	N	N	N	N	N	N	N	N	N	N	0	0%
Hip to Elbow Horizontal (mm)	N	N	N	N	N	N	N	N	N	N	0	0%

º , degrees; mm, millimeters; P, participant; Y, positive answer; N, negative answer. Only positive answers were considered for the total and the relative frequencies shown on the table.

Table 2. Mean and standard deviation data from anthropometric parameters, PSFS scores, and training characteristics of the participants

	Total (n=10)	
	Mean (SD)	Min-Max
Age (years)	47.1 (6.0)	41-46
Height (m)	1.79 (0.05)	1.72-1.85
Body mass (kg)	75.90 (8.4)	63-85.5
PSFS (points)	8.46 (2.12)	7-10
Time of sports practice (years)	8.04 (6.48)	2-30
Time in elite sport (years)	2.08 (3.66)	0-15
Weekly training frequency (sessions)	3.76 (1.31)	1-6
Mean weekly training duration (h)	8.60 (3.23)	1.5-15
Mean weekly training volume (km)	164.97 (77.02)	120-300

SD. standard deviation: Min: minir

Table 3. Mean and standard deviation data from recorded Retül variables.

	Total (n=10)	
	Mean (SD)	Min-Max
AMAX (º)	96.30 (3.47)	91-101
AMIN (º)	74.9 (6.31)	64-87
MAXKF (º)	111.3 (2.16)	109-115
MAXKE (º)	39.3 (5.48)	34-50
BA (º)	50.00 (8.19)	38-65
KFOF (º)	16.50 (13.57)	-4-39
SATW (º)	76.20 (6.43)	65-88

SD, standard deviation; Min; minimum; Max, maximum; AMAX, ankle maximum; AMIN, ankle minimum; MAXKF, maximum knee flexion; MAXKE, maximum knee extension; BA, back angle; KFOF, knee forward of foot; SATW, shoulder angle to wrist

Table 4. Reliability of the Retül system variables.

	$ICC_{3,3}$	95% CI	SEM	MDD
AMAX (º)	0.87	0.48-0.96	2.00	3.46
AMIN (º)	0.86	0.40-0.97	1.10	6.55
MAXKF (º)	0.87	0.51-0.97	0.68	2.16
MAXKE (º)	0.98	0.94-0.99	1.73	2.15
BA (º)	0.99	0.98-0.99	2.59	2.27
KFOF (mm)	0.83	0.32-0.95	4.3	15.51
SATW (º)	0.97	0.90-0.99	1.11	3.08

$ICC_{3,3}$, intraclass correlational coefficient; CI, confidence interval; SEM, standard error of measurement; MDD, minimal detectable difference; AMAX, ankle maximum; AMIN, ankle minimum; MAXKF, maximum knee flexion; MAXKE, maximum knee extension; BA, back angle; KFOF, knee forward of foot; SATW, shoulder angle to wrist.

- AMIN – peak dorsiflexion angle in the pedal stroke defined by the knee-ankle line and the heel-foot-line;
- MAXKF - peak flexion of the knee joint in the pedal stroke defined by the hip-knee line;
- KFOF - horizontal antero-posterior offset of the knee relative to the foot at 3 o'clock in the pedal stroke (90°);
- MAXKE - peak extension of the knee joint in the pedal stroke defined by the hip-knee line;
- BA - angle of the trunk relative to the horizon defined by the hip and shoulder;
- SATW - angle defined by the hip, shoulder, and wrist.

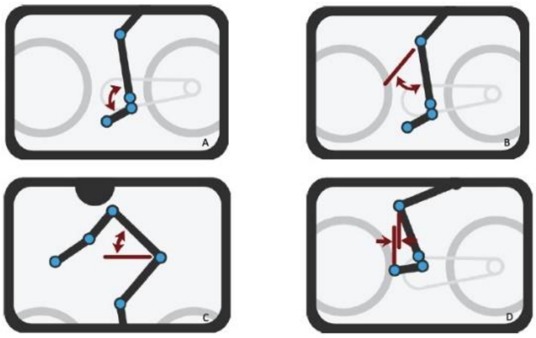

Figure 2. Representation of the Retül system variables considered for the study analysis: A - AMAX (ankle maximum) and AMIN (ankle minimum); B - MAXKF (maximum knee flexion) and MAXKE (maximum knee extension); C - BA (back angle); D - KFOF (knee forward of foot)

Data recorded from the Retül variables are shown in Table 3. Good to excellent inter-tester reliability were found for all the 7 Retül variables tested (Table 4).

4. Discussion

We investigated the reliability of the Retül Vantage motion analysis system for measuring cyclist's dynamic positioning on the bike. A survey with bike fitting experts helped us to identify the most common variables considered in the assessment of cyclists.

Overall, we observed good to excellent inter-tester reliability for all the 7 Retül variables tested. Variables that assessed peak knee extension angle, forward trunk lean angle in relation to horizon, and shoulder flexion angle showed the highest reliability values (0.98; 0.99; and 0.97, respectively). Also, the other tested variables (e.g., peak ankle dorsiflexion angle, peak ankle plantar flexion angle, peak knee flexion angle and vertical projection of the knee over the pedal axis) exhibited high reliability levels (0.87; 0.86; 0.87; and 0.83, respectively). Studies that investigated psychometric properties of kinematics systems for assessment of cyclists showed contradictory results for intra-tester reliability. Holliday et al (Holliday, Fisher, Theo, & Swart, 2017) found poor to good within-subject reliability of dynamic measurements (ICC from 0.68 to 0.87). Conversely, Fonda et al (Fonda et al., 2014) showed excellent intra-session reliability for three dynamic methods (ICC > 0.94), which is similar to our findings (ICC ranging from 0.82 to 0.99), which supports the use of motion capture system with low sampling rate such as Retül in clinical settings, especially considering 2D kinematics assessments of gross movements in the sagittal plane (Schurr, Marshall, Resch, & Saliba, 2017). It is important to highlight that the measurements in the present study also involved palpation of anatomic landmarks for marker placement, therefore, the good to excellent reliability may also depend on palpation training and following to strict operational protocols. This aspect is of concern not only for 2D systems but also for 3D systems since it can influence data acquisition because of possible errors related to soft tissue artifacts and/or marker placement inaccuracies (Niggli, Eichelberger, Bangerter, Baur, & Schmid, 2021).

Standard error of measurement (SEM) represents the amount of variation in the measurement errors for a test (Harvill, 1991). It provides a range around the observed value within which the theoretical "true" value lies. Therefore, SEM can be considered a parameter for the amount of measurement error present in an instrument and is subsequently an indicator of reliability (Geerinck et al., 2019).

In our measures, SEM calculated for each variable was lower than 3º for all angular variables, and lower than 5 mm for the linear variables. We also discuss the minimal detectable difference (MDD), also known as the smallest detectable change beyond measurement error (De Vet, Terwee, Mokkink, & Knol, 2011). The MMD values found ranged from 2.15º to 6.55º for angular variables and was 15.51 mm for the linear variable. MDD provides a value for the minimum change that must be detected in order to get confidence that the observed change is real and not, potentially, a product of measurement error in the instrument (Geerinck et al., 2019). From a more practical perspective, SEM and MDD may direct results obtained when performing movement analysis during bike fitting. After implementing changes in bike set up and re-analyzing cyclist's kinematics, in case recorded values from a specific variable fall below the SEM values, one should be cautious in considering kinematic changes as actual ones. Similarly, MDD could be considered to monitor by how much values need to change before one can be reasonably certain that a true change has occurred, that is, values need to overcome MDD for each variable.

5. Practical Applications.

The highest reliability using the Vantage system was found for BA (angle of the trunk relative to the horizon defined by the hip and shoulder). On the other hand, the lower reliability, which was still classified as good, was found for KFOF (horizontal antero-posterior offset of the knee relative to the foot at 3 o'clock in the pedal stroke). We consider these results of interest to help the implementation of the Vantage system in the kinematics assessment of bike fitting in cyclists. Moreover, the values obtained for SEM and SDC may serve as reference in the interpretation of the data obtained from Retül Vantage system.

The present study had inherent limitations. We set the cycling intensity arbitrarily at a power output of 200 W and cadence of 90 rpm assuming that differences in workload might not promote significant variation in kinematics (Bini et al., 2016). For all assessment, marker placement was performed by the same person, and the reliability outcomes may suffer influence of experimenter regarding a correct and reliable marker placement. Future studies should consider the influence of inter-examiner variability on the kinematics outcomes.

6. Conclusions

We found high and very high intra-rater reliability for kinematics variable more often included in bike fitting assessments using a Retül Vantage system. The standard error of measurements was lower than 3º for all angular kinematic variables and lower than 5 mm for the linear variable tested, with minimal detectable difference ranging from 2.15º to 6.55º for angular variables and being of 15.51 mm for the linear variable. We conclude that this system may have an acceptable level of accuracy for bike fitting purposes.

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