



A COMPARISON OF STATIC AND DYNAMIC MEASURES OF LOWER LIMB JOINT ANGLES IN CYCLING: APPLICATION TO BICYCLE FITTING

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ABSTRACT

Purpose. Configuration of bicycle components to the cyclist (bicycle fitting) commonly uses static poses of the cyclist on the bicycle at the 6 o'clock crank position to represent dynamic cycling positions. However, the validity of this approach and the potential use of the different crank position (e.g. 3 o'clock) have not been fully explored. Therefore, this study compared lower limb joint angles of cyclists in static poses (3 and 6 o'clock) compared to dynamic cycling. **Methods.** Using a digital camera, right sagittal plane images were taken of thirty cyclists seated on their own bicycles mounted on a stationary trainer with the crank at 3 o'clock and 6 o'clock positions. Video was then recorded during pedalling at a self-selected gear ratio and pedalling cadence. Sagittal plane hip, knee and ankle angles were digitised. **Results.** Differences between static and dynamic angles were large at the 6 o'clock crank position with greater mean hip angle ($4.9 \pm 3^\circ$), smaller knee angle ($8.2 \pm 5^\circ$) and smaller ankle angle ($8.2 \pm 5.3^\circ$) for static angles. Differences between static and dynamic angles ($< 1.4^\circ$) were trivial to small for the 3 o'clock crank position. **Conclusions.** To perform bicycle fitting, joint angles should be measured dynamically or with the cyclist in a static pose at the 3 o'clock crank position.

Key words: bike fitting, joint kinematics, photogrammetry, videogrammetry

Introduction

Optimal body position on the bicycle has been suggested to reduce injury risk and improve cycling performance [1, 2]. The configuration of bicycle components to the cyclist (bicycle fitting) has been usually conducted using tape measures and plumb bobs [3] with the dimensions of bicycle components related to anthropometric dimensions of the cyclist [4, 5]. For the configuration of bicycle components (e.g. vertical and horizontal positions of the saddle), joint angles have been preferably recommended in comparison to anthropometric references [6]. The reason is that length based references for saddle height configuration does not take into account particular differences in thigh, shank and foot length. The effectiveness of the “optimum” relationship between bicycle components and body dimensions failed to result in similar body positions because joint angles have not been taken into account. An optimal combination of hip, knee and ankle joint angles would indeed result in optimal power production from the lower limb muscles.

In cycling the use of video analysis to optimize the configuration of bicycle components is increasing [7, 8]. However, all guidelines are based on measurements of the cyclist in static poses without information on potentially optimum joint angles from dynamic assessments. Burke and Pruitt [3] suggested that knee flexion angle should be between 25–30° when the pedal is static at the

bottom of the crank cycle (6 o'clock crank position) for an optimum saddle height configuration. Yet, Peveler et al. [7] showed that the knee flexion angle measured statically at the 6 o'clock crank position underestimated the knee flexion angle taken during cycling motion by ~17%. Their result indicates that another approach should be taken to ascertain the saddle height by using either a dynamical assessment or a static measure in a different crank position (whenever video analysis is not possible). Assuming that the peak crank torque is applied close to the 3 o'clock crank position [9] and that leads to peak patellofemoral compressive force [10], this position could be used rather than the 6 o'clock crank position. Also, the 3 o'clock crank position has been used to ascertain the forward-backward saddle position [11] and that is closer to the knee joint angle of optimal quadriceps muscle force production for cyclists [12].

Given previous studies showed that knee flexion angles are larger at dynamic compared to static assessments of cyclists [7, 8], a comparison between static and dynamic analyses of joint angles for optimization of bicycle components have not fully being explored. This comparison could show that a static position of cyclists (i.e. at 3 o'clock crank angle) could be valid to replicate joint angle observed during cycling motion. Clinicians that do not have access to motion analysis systems could then benefit by using a single digital still camera to capture images from cyclists at a given position on their bicycles. Bicycle saddle position (vertical and fore-aft) could then be configured more properly, leading to an improvement in bike fitting methods.

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Thus, the aim of this study was to compare lower limb joint angles of cyclists in static postures compared to dynamic cycling. This comparison would indicate if joint angles taken during static poses at the 3 o'clock crank position would replicate a dynamic cycling motion. The hypothesis was that cyclists would replicate similar joint angles in static poses only at the 3 o'clock crank position.

Material and methods

Design

All cyclists attended one evaluation session (cross-sectional) where anthropometric measures, images from static postures (photogrammetry) and dynamic cycling from video (videogrammetry) from their right sagittal plane were collected. They did not have the configuration of their bicycles changed throughout the study to avoid changing their preferred set up and affect their preferred muscle recruitment.

Participants

Thirty cyclists with experience ranging from recreational to competitive volunteered to participate in the study. The characteristics of the cyclists were (mean \pm SD) 39 \pm 10 years old, 80 \pm 15 kg body mass, 177 \pm 8 cm height, 7.3 \pm 3.8 hours/week cycle training, and 8 \pm 7 years cycle experience. Prior to the study participants were informed about possible risks and signed a consent form approved by the Ethics Committee of Human Research where the study was conducted in accordance to the declaration of Helsinki.

Procedures

As landmarks for the hip, knee and ankle joint axes, reflective markers were placed on the right side of the cyclists at the greater trochanter, lateral femoral condyle, and lateral malleolus (see Figure 1). Two markers were attached to the pedal to compute the pedal axis and one marker was attached to the bottom bracket to determine the crank axis. Two markers were taped at a known distance on the bicycle frame for linear image calibration in metric units. The distance from the camera to the bicycle and zoom setting were defined to reduce the motion of the cyclists in the edges of the image frame as an attempt to reduce non-planarity errors in angle computation (for details see Page et al. [13] and Olds and Olive [14]).

Cyclists had their own bicycles mounted on a wind trainer (Kingcycle, Buckinghamshire, UK), and were asked to assume a position as similar as possible to outdoors cycling. A digital camera (Samsung ES15, Seoul, South Korea) recorded three high resolution images

(3600 \times 2400 pixels of resolution) from the sagittal plane with the cyclists standing on the floor (calibration image), cyclists seated on the bicycle with the right crank in the most forward position (3 o'clock) and the right crank in the lowest position on the crank cycle (6 o'clock). One image was recorded at each position to simulate common procedures used in bicycle fitting configuration when a cyclist's knee flexion angle is measured using a manual goniometer [3, 15]. Cyclists were then asked to select a gear ratio and assume pedalling cadence as similar as possible to steady state cruising road cycling for five minutes simulating regular long distance training. After three minutes of riding, video was recorded for 20 s using the same digital camera (30 Hz, 640 \times 480 pixels of resolution) which was shown to provide reliable measurements of rearfoot timing variables (e.g. time of maximal eversion) during running in a previous study [16]. The digital camera used in our study enabled picture capture in high resolution and video recording at regular frame rate and resolution similar to cameras used in motion analysis systems (i.e. 1 mega pixel). Assuming that cyclists would freely choose pedalling cadence close to 90 rpm, we expected that our resolution for crank angle definition would be of 18° per crank revolution and consequently of 3.6° for averages of five crank revolutions.

Hip, knee and ankle joint angles were manually digitized from the static postures and video files using ImageJ (National Institute of Health, USA) by the same rater for the 30 cyclists. Joint angles definitions are illustrated in Figure 1. For dynamic cycling, frames taken from five consecutive crank revolutions where cyclists were at the 3 o'clock and at the 6 o'clock crank positions were visually selected to compute joint angles. The average of five revolutions of each joint angle was used for comparison with static poses. The rater's reliability in digitising was determined using images from static poses analysed on day one and day seven (see results in Table 1). Average pedalling cadence was computed for each cyclist from the time difference taken to cover five consecutive revolutions.

Statistical analyses

Inferential statistics can be prone to error. Low power of tests would preclude extrapolation of results to a wider population using inferential statistics. Therefore, we used effect sizes opting for a threshold of large effects ($ES = 1.0$) for substantial changes. This is a more conservative approach than previously described [17], but it would ensure a non-overlapping in distribution of scores greater than 55% [18]. For comparison of measures taken in each image, typical errors were computed as the ratio between the standard deviation from the differences between days and the square root of "2" ($TE = SD_{diff}/\sqrt{2}$ – see Hopkins [19] for details).

Cyclists' means and confidence limits (computed for $p < 0.05$) were reported for both static and dynamic hip, knee and ankle angles. To compare static and dynamic angles (i.e. hip, knee and ankle), Cohen's effect sizes (ES) were computed for the analysis of magnitudes of the differences between the two methods and were rated as trivial ($d < 0.25$), small ($d = 0.25-0.5$), moderate ($d = 0.5-1.0$), and large ($d > 1.0$) [20]. Mean differences and standard deviation from the differences between the joint angles measured in static and dynamic positions were computed to illustrate the agreement between methods, following description from Bland and Altman [21].

Results

Differences in measuring joint angles were trivial between days ($< 4.5\%$) for hip, knee and ankle angles

based on analysis of Cohen's effect sizes (see Table 1). Within cyclists coefficient of variation of joint angles taken across five crank revolutions was lower than 5%. Errors in determination of the 3 o'clock and the 6 o'clock crank positions in video files were $< 1^\circ$ ($< 1\%$) and 3° (2%), respectively.

Freely chosen pedalling cadence was 85 ± 11 rpm for all cyclists. The differences between static and dynamic angles were large at the 6 o'clock crank position with greater hip angle ($4.9 \pm 1^\circ$), smaller knee angle ($8.1 \pm 2^\circ$) and smaller ankle angle ($8.5 \pm 2^\circ$) for static angles.

The differences between static and dynamic angles ($< 2.5^\circ$) were trivial to small for the 3 o'clock crank position (see Figure 1 and Table 2). In Figure 2, we illustrate the mean differences between joint angles measured in static and dynamic positions and the standard deviation from differences for the 6 o'clock and the 3 o'clock crank positions using the Bland-Altman's plot [21].

Table 1. Intra-rater variability (between days comparison) in the analysis of images from static postures reported as typical error of measurements and effect sizes of the hip, knee and ankle angles at the 6 o'clock and at the 3 o'clock positions of the pedal

	Between day difference (degrees)	Between day difference (%)	Typical error (degrees)	ES	ES – magnitude inference
3 o'clock position					
Hip angle	0.03°	0.61	0.14	0.01	Trivial
Knee angle	0.05°	0.46	0.09	0.01	Trivial
Ankle angle	0.98°	4.51	1.25	0.13	Trivial
6 o'clock position					
Hip angle	0.05°	0.48	0.12	0.03	Trivial
Knee angle	0.25°	0.42	0.12	0.01	Trivial
Ankle angle	0.84°	4.01	0.58	0.17	Trivial

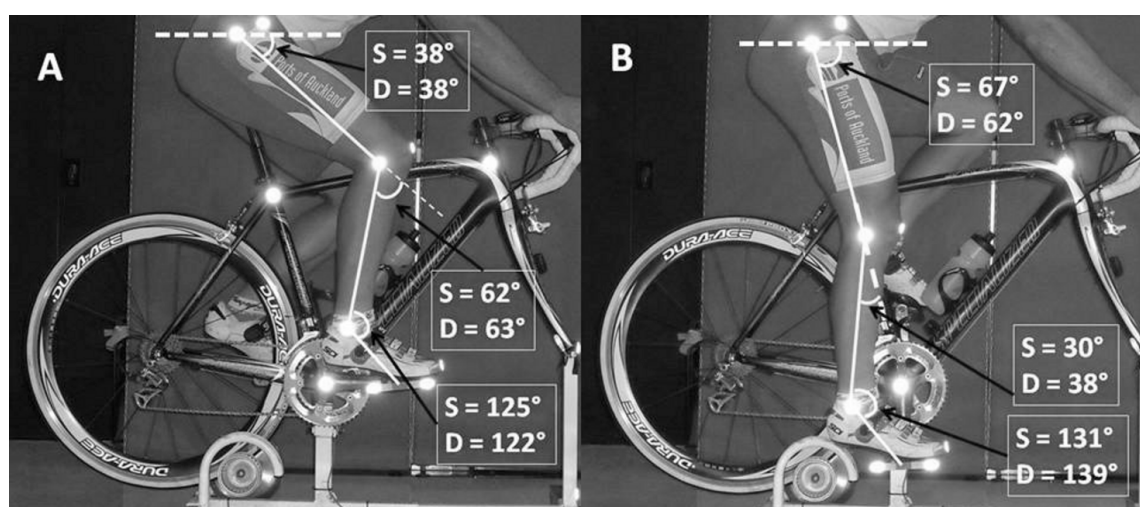


Figure 1. Illustration of reflective marker placement on the right side of the cyclist at the greater trochanter, lateral femoral condyle and lateral malleolus to indicate hip, knee and ankle joint angles. Markers attached to the pedal were used to compute the pedal axis for ankle joint measurement. Mean hip, knee and ankle joint angles are shown for the 30 cyclists for static (S) and dynamic (D) measurements at the 3 o'clock (A) and 6 o'clock (B) crank positions.

Table 2. Hip, knee and ankle angles (mean \pm confidence interval – CI) at the 3 o'clock and 6 o'clock crank positions for 30 cyclists. Comparison of the angles determined by static and dynamic methods using effect sizes (ES)

	Difference between static and dynamic angles				
	Static angle (degrees)	Dynamic angle (degrees)	Degrees	ES	ES – magnitude inference
3 o'clock crank position					
Hip angle	38 \pm 1.3	38 \pm 1.1	0.3 \pm 1.1	0.1	Trivial
Knee angle	62 \pm 1.7	63 \pm 1.5	1.1 \pm 1.6	0.3	Trivial
Ankle angle	125 \pm 2.4	122 \pm 2.2	2.5 \pm 2.5	0.4	Small
6 o'clock crank position					
Hip angle	67 \pm 1.8	62 \pm 1.4	4.9 \pm 1.1	1.1	Large
Knee angle	30 \pm 2.4	38 \pm 1.5	8.1 \pm 1.9	1.5	Large
Ankle angle	131 \pm 2.1	139 \pm 2.4	8.5 \pm 1.9	1.4	Large

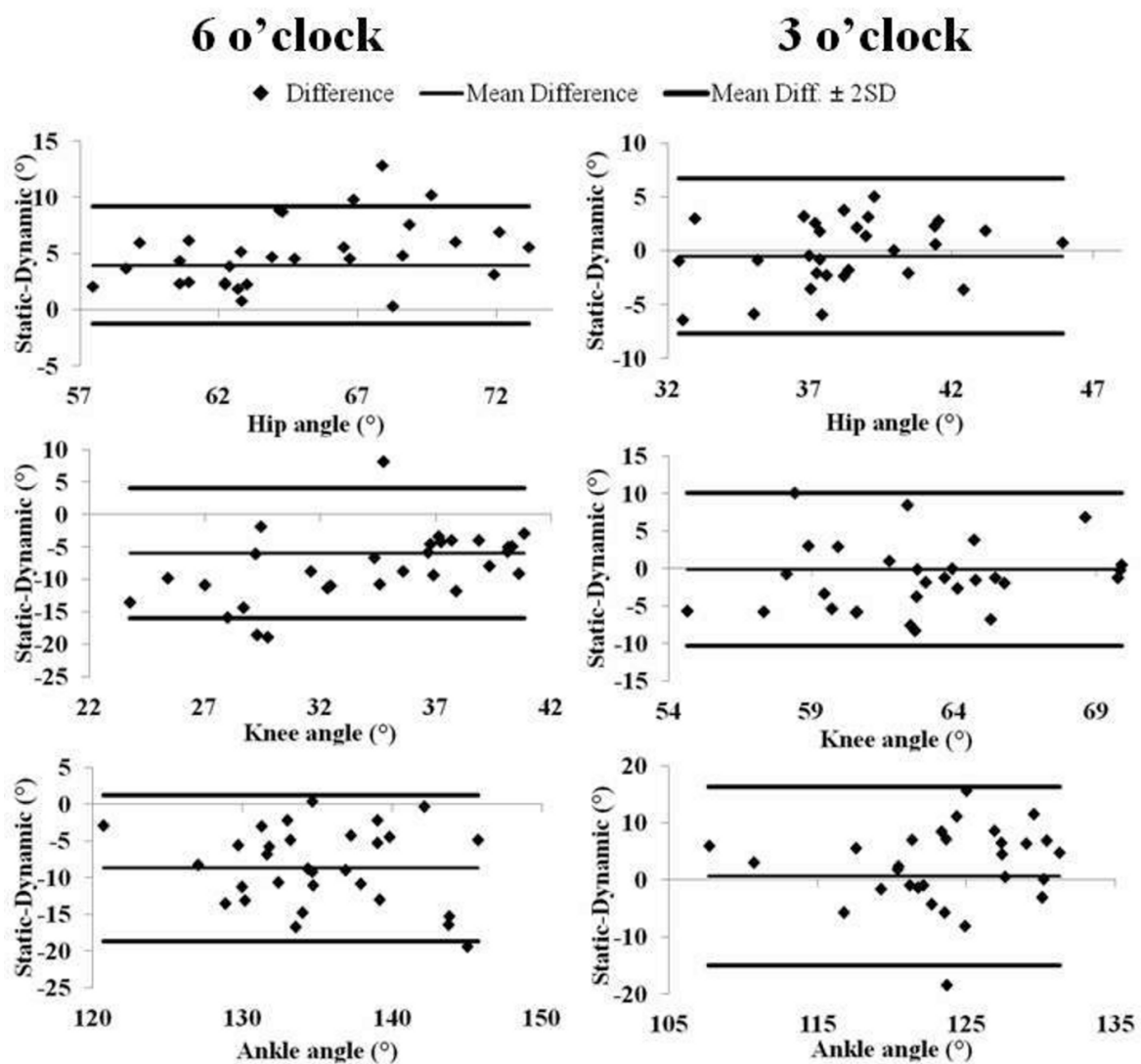


Figure 2. Differences between measures (individual scores), mean differences between joint angles measured in static and dynamic positions and the standard deviation from differences for the 6 o'clock and the 3 o'clock crank positions using the Bland-Altman's plot [21]

Discussion

In bicycle shops, clinics and bicycle research, configuration of bicycle components to the cyclist (bicycle fitting) takes into account lower limb joint angles determined from a static position of cyclists at the 6 o'clock crank position measured once [3, 11]. However, cycling is a dynamic movement, so bicycle configuration should ideally be based on dynamic assessment looking at the average of consecutive pedal revolutions. Our study reported differences between lower limb joint angles gathered from cyclists in static postures compared to dynamic cycling. Cyclists in our study did not replicate similar angles in static postures as those observed in video analysis when the crank was at the 6 o'clock crank position. Given the fact that the static 6 o'clock crank angle method is commonly used in bicycle shops and clinics, the results of the current study showed that the 3 o'clock position would be a better method to set-up a cyclist on a bicycle if dynamic cycling angles are not available.

The measurement of joint angles in images of cyclists on their own bicycles has the potential to improve the existing techniques for bicycle configuration components optimization [15]. Joint angles are important variables for the configuration of bicycle components to help reduce injury risk and optimize performance [6, 22], but the assessment of joint angles of cyclists may depend on exercise conditions. Previous studies presented the dependence of joint angle on workload level [23], pedalling cadence [24], fatigue state [25] and experience in cycling [26]. Therefore, these factors should ideally be taken into account when providing a bicycle set-up.

Farrell et al. [27] reported that configuring saddle height to elicit 25–30° of knee flexion using a goniometer with the cyclist in a static pose at the 6 o'clock crank position resulted in 30–45° knee flexion at the same 6 o'clock crank position in video analysis. The larger knee flexion angles (~10°) in dynamic cycling reported by Farrell [27] and Peveler et al. [7] using the goniometer method were also evident in our study ($8.2 \pm 5^\circ$) using the digitisation of the static pose to determine knee flexion angle at the 6 o'clock crank position. Therefore, one has to be careful that the static recommended angles might result in different joint angles than the ones intended for cycling motion.

Greater hip angle (smaller flexion), smaller knee angle (smaller flexion) and smaller ankle angle (greater flexion) were observed in static poses at the 6 o'clock crank position compared to the dynamic assessment in our study. Looking at the main driving muscles of cycling (hip and knee joint extensors and ankle plantar flexors), hip and knee joint extensors may be shorter and ankle plantar flexors may be longer in the static pose at the 6 o'clock crank position compared to the one during dynamic cycling due to smaller flexion angles. These differences may affect muscle tendon-unit length and force production [28].

Differences in joint angles between static and dynamic analysis may be related to the lack of angular momentum at the 6 o'clock crank position during static poses, which is contrary to what is observed during dynamic cycling. For pedalling at 90 rpm, cyclists usually present ~27% greater angular velocity of the crank at the 12 o'clock and 6 o'clock crank positions compared to the average angular velocity of the revolution [29]. Two reasons may explain the similarities of the static and dynamic joint angles at the 3 o'clock crank position: 1) There is ~28% lower angular velocity in dynamic cycling at the 3 o'clock crank position than the average angular velocity over the entire revolution of the crank [29]; and 2) To sustain the cranks horizontally at the 3 o'clock crank position, cyclists need to balance the mass of the ipsilateral and contralateral legs.

In terms of saddle height adjustment, a range of 25–30° of knee flexion has been recommended to improve efficiency and reduce the risk of injuries in cyclists [22]. Reductions of ~8° may be expected for the knee flexion angle of cyclists assessed statically at the 6 o'clock position in comparison to dynamic assessment. Therefore setting the saddle height by a static pose of the cyclist taken at the 6 o'clock position would generally result in a lower saddle height than the one taken dynamically. Depending on the existing saddle height, suboptimal muscle length for force production and increased compressive knee forces would be observed using a lower saddle height [22]. Although the goal of the current study was not to determine recommendations for bicycle fitting, it would be ideal to match the knee flexion angle for optimal torque production (~60–80°, see Folland and Morris [30]) to the one observed at the optimal crank angle for torque production (i.e. 3 o'clock). Future research should be conducted to ascertain on what ranges of hip, knee and ankle angles taken together would optimize cycling performance.

The choice of using the same camera to acquire video and capture images of the cyclists in static poses had positive and negative effects in our study. One benefit was that there was no effect from different lenses on image distortion. However, the camera used in the present study was not capable of recording images and video at the same resolution (which would be similar to cameras used by bicycle shops providing bicycle configuration services). Video images had ~19% of the resolution of the static images, which may have reduced the precision of tracking markers in video images compared to images from static poses. However, the choice for analysis of mean results of joint angles over five crank revolutions increased the accuracy of crank angle determination for joint angle computation.

Sources of error using sagittal plane video may be out of plane movements and linear image calibration. In cycling, most movement can be assessed via sagittal plane analysis, but up to 10% of differences may be expected for the hip angle when measuring from the

sagittal plane compared to 3D analysis [31]. Pelvic motion during cycling may also affect the comparison of images from static and dynamic analyses. Horizontal (± 5 cm) and vertical (± 2 cm) motion of the hip joint occurs during stationary cycling [32] which may affect lower limb joint angles especially for cyclists using a higher saddle height. Therefore, bicycle set-up should ideally use images from both sagittal and frontal planes or 3D analyses.

Conclusions

Cyclists did not replicate in a static pose at the 6 o'clock crank position similar hip, knee and ankle joint angles as measured in dynamic cycling. To perform configuration of bicycle components using joint angles, measurements should be taken dynamically or with the cyclists in static poses at the 3 o'clock crank position, instead of the usually recommended 6 o'clock crank position.

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