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Original Research

# Anthropometrics, flexibility and training history as determinants for bicycle configuration

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## ABSTRACT

Intrinsic factors such as leg length, arm length, flexibility and training history are factors that may be relevant to the optimisation of the individual bicycle configuration process. Bike fitting methods do not always take all these variables into account, and as yet there have been limited studies examining how these variables can affect the cyclist's position on the bicycle. The main aims of this study were to establish how individual anthropometrics, training history and flexibility may influence cyclists' freely chosen bicycle configuration, and to determine the full-body static flexion angles chosen by cyclists on the bicycle.

Fifty well-trained male cyclists were recruited for the study. A multivariate linear regression analysis was performed to predict the four main configurations of a bicycle (saddle height, saddle setback, handlebar reach and handlebar drop) based on individual anthropometrics, flexibility and training history. Average joint kinematic ranges for the knee (36°±7°) and elbow (19°±8°) joint supported previous recommendations. Hip (77°±5°) and shoulder (112°±7°) joint angles should be determined as true clinical joints.

Trochanteric leg length ($p < 0.01$), Knee Extension Angle test ($p < 0.01$) and mSchober test ($p = 0.04$) were significant predictors for determining saddle height. Hamstring flexibility can be used to predict handlebar drop ($p = 0.01$).

A cyclist who wishes to adopt a more aerodynamic position with an increased handlebar drop should aim to improve their hamstring flexibility.

## Introduction

Bike fitting is defined as the detailed process of evaluating the cyclist's physical and performance requirements and systematically adjusting the bike to meet the cyclist's goals and needs.[1] Bicycle configuration can have an influence on the cyclist's performance and perception of comfort.[2] Most studies to date have discussed the normative values or ranges of bicycle configuration that are recommended for power and injury prevention (see Table 1 and Table 2 for a summary). An online survey identifying factors of bicycle comfort found that, of the 244 respondents, 90% of the cyclists agreed that comfort is a major concern when riding a bicycle, while 46% of enthusiastic cyclists agreed that comfort is likely achieved at the expense of performance.[3] It is therefore important to address the adjustable components of the bicycle and the cyclists' anthropometrics as well as their perceptions of comfort when optimising their cycling position.

To increase performance and prevent injuries, it has been recommended that saddle height be set using a static knee flexion angle (KFA) of 25°–35° with the pedal and foot at the bottom dead centre.[4] Subsequent studies have demonstrated that this range coincides with optimal power production and economy.[5,6] This range has subsequently been adopted as a form of a gold standard for setting saddle height.[7] Adjustments are often made within the range to accommodate for individual movement patterns and anthropometric characteristics of the cyclists or their injury history.[8]

Other joints of the body and configuration variables should have similar recommended ranges for optimal bicycle configuration. However, until recently there have been no studies describing the recommended ranges for the other joints of the body.[9] A recent study of 19 well-trained cyclists assessed the mean and standard deviation (*SD*) for 5 major joint angles (knee, hip, ankle, shoulder and elbow) in the cyclists' freely chosen position,[10] and more recently how these angles change with increased intensity.[11] Additional guidelines for ankle and elbow ranges have been published, although these are based on personal experience rather than scientific data (Table 2).

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**Abbreviation list**

| | |
|---|---|
| $\dot{V}O_{2peak}$ | Peak oxygen consumption |
| cm | centimetre |
| KEA | Knee extension angle |
| KFA | Knee flexion angle |
| kg | kilogram |
| KOPS | Knee over pedal spindle |
| PAR-Q | Physical Activity Readiness Questionnaire |
| PPO | Peak Power Output |
| rpm | revolutions per minute |
| s | seconds |
| SD | Standard deviation |
| W | Watts |

**Table 1**
Summary of guidelines for other variables of bicycle configuration.

| Variable | Recommendation | Based upon | Study |
|---|---|---|---|
| **Saddle height** | 25°-35° knee flexion angle at bottom dead centre (static) | Scientifically based | (Bini et al., 2011; Holmes et al., 1994; Peveler, 2008; Peveler et al., 2005, 2007; Peveler & Green, 2011) |
| **Saddle setback** | Formula related to upper leg length | Personal perspective | (de Vey Mestdagh, 1998) |
| | Plumbline and knee over pedal spindle in the 3 o'clock position (static) | Personal experience and recommendations | (Burke, 2003; Burt, 2014; Silberman et al., 2005) |
| **Handlebar reach** | Formula determined by arm length and torso length | Personal perspective | (de Vey Mestdagh, 1998) |
| | Plumbline from cyclist's nose dropped to centre of stem, hands in drops | Personal experience and recommendations | (Burke, 2003) |
| | Comfort in the drops, elbows flexed 60° to 70°<br>With the knees at their maximal height and forward position, the distance between the elbows and knees should be small, 1–2 inches (2–5 cm) | Personal experience and recommendations | (Silberman et al., 2005) |
| | Related to forearm length | Personal experience and recommendations | (Pruitt & Matheny, 2006) |
| | Individual, comfort | Personal experience and recommendations | (Burt, 2014) |
| **Handlebar height** | Formula determined by arm length and torso length | Personal perspective | (de Vey Mestdagh, 1998) |
| | 2.5 cm–5 cm below saddle for small cyclists<br>10 cm below saddle for tall cyclists | Personal experience and recommendations | (Burke, 2003) |
| | Hands on the brake hoods, arms slightly flexed, the torso should flex to about 45° in relation to a non-sloping top tube | Personal experience and recommendations | (Silberman et al., 2005) |
| | Racer and competitive recreational cyclists' torso angle 30°–45°<br>Casual cyclist 50°–60° torso angle | Personal experience and recommendations | (Pruitt & Matheny, 2006) |
| | Individual, comfort | Personal experience and recommendations | (Burt, 2014) |

De Vey Mestdagh[12] has suggested formulae to determine the various contact points of the bicycle such as saddle setback, handlebar reach and handlebar drop. However, most bike fitting experts have suggested that the final position should rather be based on comfort and what appears subjectively acceptable (Table 1). A potential limitation to using relatively simple formulae is that they do not always take into consideration all of the individual anthropometric segments (eg upper and lower leg), flexibility or pedaling techniques.[6,13]

Saddle setback has commonly and anecdotally been determined by the 'knee over pedal spindle' or 'KOPS' method.[14–16] This involves dropping a plumbline from the anterior knee (tibial tuberosity) while the crank and pedal are positioned in the most forward or 3 o'clock position. The plumbline is recommended to fall in line with the pedal axle or just posterior to this. This method has not been validated scientifically and although it has been suggested that this prevents knee injury, there is no data to support this.[17,18] Another formula that is used takes the femoral length into account in determining optimal position.[12]

There are two popular methods for setting handlebar reach and handlebar drop, however, neither have any scientific support (Table 1). The first determines the final handlebar position as a measure of the arm and torso length.[15] De Vey Mestdagh[12] in his personal search for an optimum cycling position, determines handlebar reach and handlebar drop values by measuring arm and torso length, with recommended heights determined by averages as well as comfort levels. In a pilot study investigating comfort and the validity of a commercial bicycle fitting system, there was no direct relationship between body segments and preferred handlebar position.[19]

The other most common method of setting handlebar reach and handlebar drop is related to static torso angle, with a recommendation ranging from 30° to 60°.[15,16,20] The torso angle is measured as an angle from a line parallel to the floor bisecting a line from the hip joint centre to the glenohumeral joint centre.[15,16,20] This angle negates the natural curves of the lumbar and thoracic spine and the multiple intervening joints. However, these same authors have suggested that handlebar height also depends on training status, strength, individual comfort, and spinal and hamstring flexibility.

It has previously been reported that cyclists with reduced hamstring flexibility tended to select lower saddle heights.[21,22] However, Hynd, Crowle and Stephenson[23] determined that hamstring flexibility did not have an effect on self-selected saddle height. It has previously also been demonstrated that cyclists with reduced hamstring flexibility tend to adopt a kyphotic lumbar spine posture.[24] This may be due to the hamstrings biarthrodial nature and attachment on the ischial tuberosity, as they are stretched during the pedal revolution there is a direct influence on pelvic rotation.[25] In a study of young athletes which examined the effects of hamstring extensibility on spinal curvatures, when the pelvis was positioned in a posteriorly rotated position, the subjects thoracic flexion increased in order to reach greater distance in the sit and reach test.[26] Similarly, a greater lumbar flexion and an anteriorly rotated pelvis were linked to a greater handlebar drop position.[27] From this we can hypothesise that handlebar reach and handlebar drop may be determined by both hamstring and spinal flexibility. Ferrer- Roca et al.[21] suggested that further studies should be conducted to determine if low-level hamstring flexibility may have an influence on the cyclist's posture and bicycle configuration. Likewise, Sauer et al.[28] and Kotler et al.[29] both concluded that when configuring an individuals' bicycle, their range of motion and flexibility should be assessed.

Time spent on the bike has previously been demonstrated to be a better determinant of saddle height than hamstring flexibility.[23] Both McEvoy[30] and Muyor et al.[27] determined that elite cyclists had a greater anterior pelvic tilt, and that this was due to time adaptation on the bike.

**Table 2**
Previously recommended static ranges for optimal positioning.

| Joint | Recommendations | Based upon | Study |
|---|---|---|---|
| Ankle | 13° plantarflexion at bottom dead centre | Personal perspective | (de Vey Mestdagh, 1998) |
| | 5°-15° plantarflexion at bottom dead centre | Personal experience and recommendations | (Burt, 2014) |
| Knee | 25°-35° flexion at bottom dead centre | | (Bini et al., 2011; Holmes et al., 1994; Peveler, 2008; Peveler et al., 2005, 2007; Peveler & Green, 2011) |
| Hip | 55°-65° on road bike (measured as an angle along the femur to the greater trochanter to the shoulder, top dead centre) | Personal experience and recommendations | (Burt, 2014) |
| Shoulder | None to date | | None to date |
| Elbow | 20°-30° hands on hoods | Personal experience and recommendations | (Burt, 2014) |
| Torso angle | 45°-55° recreational, hands on hoods<br>45°-30° fast road cyclists, hands on hoods | Personal experience and recommendations | (Burt, 2014) |
| | 45° to non-sloping top tube, hands in drops | Personal experience and recommendations | (Silberman et al., 2005) |
| | 30°-45° racing or competitive recreational<br>40°-50° fitness cyclists<br>50°–60° casual cyclists<br>Hands on hoods | Personal experience and recommendations | (Pruitt & Matheny, 2006) |

Due to the repetitive pedaling movement of cycling during training, there is likely a neuromuscular adaptation which results in a more skilled muscle recruitment in highly trained compared to novice cyclists.[31] Cycling experience and level of expertise is therefore another factor that may contribute to a better pedaling technique.[32] Further studies have been suggested in order to establish if flexibility, history of cycling and training load are determinants for bicycle configuration.[21,27,33]

Dahlquist, Leisz, and Finkelstein[34] investigated the performance of 63 recreational road cyclists compared with established norms regarding strength and flexibility measures. Hamstring and lumbar flexibility were tested, as well as static goniometer measurements of the torso, elbow, hip and knee angles on their own bicycles. Despite 59% of the participants having had a professional bike fit, less than 50% of the participants met the recommended flexibility, strength and bike fit norms. The professional fitments conducted varied from visual inspection to computerised systems, and some cyclists were fitted for optimal performance and aerodynamics, resulting in a degree of discomfort. The study concluded that further studies should be conducted as there is a need for better definitions of normative values for intrinsic factors related to cycling.

Our aims were therefore:

- To determine the degree to which the four main elements of freely chosen bicycle configuration (saddle height, saddle setback, handlebar reach and handlebar drop) are associated with the following:
  A) individual anthropometrics: stature, trochanteric leg length and arm length
  B) flexibility: Knee Extension Angle test, Fingertip to floor and modified Schober test, and
  C) Training history and training volume
- To determine the static joint kinematics of the ankle, knee, hip, shoulder and elbow adopted by cyclists.

**Table 3**
Minimum, maximum and mean ± standard deviation of general characteristics, bicycle configurations, joint angles, flexibility results and training history of participants ($n = 50$).

| Variable | Minimum | Maximum | *Mean ± SD* |
|---|---|---|---|
| Age (years) | | | 30 ± 9 |
| Body mass (kg) | | | 76.5 ± 7.9 |
| Stature (cm) | | | 180.7 ± 5.6 |
| Trochanteric leg length (cm) | | | 97.5 ± 4.4 |
| Percentage body fat (%) | | | 11.9 ± 4.7 |
| Sum of seven skinfolds (mm) | | | 61.5 ± 20.2 |
| PPO (W) | | | 387.7 ± 53.1 |
| PPO (W/kg) | | | 5.1 ± 0.7 |
| $\dot{V}O_{2max}$ (ml/kg/min) Relative | | | 58.8 ± 7.7 |
| **Bicycle configuration** | | | |
| Saddle height (seat height + crank length, mm) | 870 | 1040 | 942.8 ± 37.4 |
| Saddle height as a % of leg length | 93.9 | 103.3 | 97.1 ± 2.2 |
| Setback as a % of seat height | 5.8 | 15.1 | 10.3 ± 2.3 |
| Drop as a % of seat height | 1.7 | 21.5 | 13.0 ± 3.6 |
| Reach as a % of stature | 33.8 | 38.8 | 35.9 ± 1.2 |
| **Joint angles** | | | |
| Ankle (°) | 97 | 133 | 116 ± 7 |
| Knee (BDC, °) | 20 | 51 | 36 ± 7 |
| Hip (TDC, °) | 67 | 86 | 77 ± 5 |
| Shoulder (°) | 99 | 129 | 112 ± 7 |
| Elbow (°) | 3 | 45 | 19 ± 8 |
| **Flexibility** | | | |
| Knee Extension Angle (°) | 8 | 80 | 47 ± 16 |
| Fingertip to floor (cm) | −14.50 | 29.00 | −0.18 ± 9.61 |
| Modified Schober (cm) | 20.00 | 25.00 | 21.88 ± 0.91 |
| **Training History** | | | |
| Consecutive years of training (yrs) | 1.50 | 24.00 | 5.97 ± 4.21 |
| Average hours of training per week in last 3 months (h) | 4.00 | 20.00 | 11.04 ± 3.79 |

BDC = bottom dead centre. TDC = top dead centre.

We hypothesised that saddle height, saddle setback and handlebar reach would be significantly associated with leg length and arm length. Hamstring flexibility was predicted to be associated with a higher saddle height, a longer handlebar reach and a greater handlebar drop. Spinal flexibility was predicted to be associated with a longer handlebar reach and greater handlebar drop. Lastly, the influence of an increased training history or training load was expected to be associated with both a lower handlebar drop and a higher saddle height.

## Materials and methods

### *Participants*

Fifty well-trained male road cyclists (30 ± 9 years, 76.5 ± 7.9 kg, 180.7 ± 5.6 cm) conforming to Level 2 (recreationally trained, relative Peak Power Output > 3.6W/kg) or greater[35] were recruited for this study. The general characteristics and performance parameters of the 50 cyclists are shown in Table 3. Participants were excluded if they had made any changes to their bicycle configuration in the past three months (either on their own accord or by having a bike fit), and if they experienced any pain or discomfort on their current bicycle configuration. Prior to testing, each participant was informed of the risks and stresses associated with participation in the research trial, completed a Physical Activity Readiness Questionnaire (PAR-Q)[36] and signed an informed consent form.

The study was approved by the Human Research Ethics Committee of the Faculty of Health Sciences of the University of Cape Town (648/2014), and conformed to the principles of the World Medical Association Declaration of Helsinki.[37]

### *Testing procedure*

The participants reported to the laboratory with their own bicycle, cycling shoes and pedals. During the visit to the laboratory, participants were personally interviewed about their training history, including questions such as how many consecutive years they have cycled for and how many training hours on average they are completing (per week for the past three months). Stature (standing height) was measured using a recently calibrated portable stadiometer (Seca scale, California, USA). Body mass was measured, using a recently calibrated portable scale (Seca scale, California, USA). Leg length was measured from the most prominent aspect of the greater trochanter as measured in the midsagittal plane, through the lateral ankle malleolus to the base of the heel. The arm length was measured from the tip of the acromion to the tip of the 3rd finger with all joints in neutral. The sum of seven skinfolds (triceps, biceps, supra-iliac, sub-scapular, calf, thigh and abdomen) were taken with the use of a skinfold caliper (Harpenden skinfold caliper, West Sussex, UK) and body fat percentage was determined.[38]

The participants then underwent the following flexibility testing:

1. Knee Extension Angle (KEA) test
2. Fingertip to floor test
3. Modified Schober test

See **Appendices** for detailed descriptions of testing.

The participant's own bicycle configuration was measured according to a set of objectively reproducible measurements as previously described[10] and detailed in the Appendices:

- Saddle height

The saddle height was measured from the centre of the crank axle to the top of the saddle, passing through a reference line set at 74° to the horizontal to standardise the seat tube angle.

- Saddle setback

Saddle setback was measured as the horizontal distance from the front of the saddle to the centre of the crank axle. The front of the saddle was determined based on a standardised distance of 22.5 cm from the contact point of the ischia to the front of the saddle. For saddles which did not conform to these measurements, a correction value was applied to the measured setback.

- Handlebar reach

The handlebar reach was measured horizontally, from the centre of the handlebar clamping point to the centre of the 74° seat tube reference line.

- Handlebar drop

Handlebar drop values were measured as the vertical distance from the top of the saddle surface to the centre of the handlebar clamping point.

- Crank length

Static joint angles of the ankle, knee, hip, shoulder and elbow were taken with the participant seated on the bicycle using a digital inclinometer (Digi-Pas® DWL-90E model) as previously described by Holliday et al. (2017) and detailed in the appendix. Knee flexion angle was assessed by requesting the subject to stop pedaling with the pedal at the bottom of the pedal stroke in the 6 o'clock position, without altering their natural ankle angle. The tester was subjectively assessing that the heel was not dropped as the cyclist adopted a resting position. A CycleOps 400 Indoor Pro Cycle (Power Tap: Saris Cycling Group. Madison, WI. USA) was used for the purpose of a follow-on study. All measurements were taken by the primary investigator and repeated until three consistent measures were recorded. Saddle height, saddle setback, handlebar reach, and handlebar drop were set to match the configuration of the participant's own bicycle.

This was followed by an incremental exercise test to volitional exhaustion to determine eligibility in the study. The participants performed a standard warm-up and after a 3 min rest period completed a Peak Power Output (PPO) and Peak Oxygen Consumption ($\dot{V}O_{2peak}$) test. The CycleOps VirtualTraining app (VirtualTraining, version 1.7.3, Czech Republic) was used to control the ergometer and set the resistance. Heart rate was captured using a Suunto™ T6C heart rate monitor (Suunto Oy, Vanata, Finland). Gas analysis was monitored over 15 s intervals using an on-line breath-by-breath gas analyser and pneumotach (Oxycon, Viasis, Hoechberg, Germany). Participants started exercising at a workload of 100 W and resistance was increased by continuous ramp protocol at a rate of 20 W every 60 s until the participant was exhausted and could not sustain a cadence of at least 60 revolutions per minute (rpm). PPO was calculated by averaging the power output for the final minute of the $\dot{V}O_{2peak}$ test. $\dot{V}O_{2peak}$ was recorded as the highest $\dot{V}O_2$ reading recorded for 30 s during the test. Maximum heart rate was recorded as the highest heart rate achieved during the incremental exercise test.

### *Statistical analysis*

Four standard multivariate linear regressions were performed to predict the four main configurations of a bicycle (relative values for: saddle height, saddle setback, handlebar reach and handlebar drop) based on individual anthropometrics, flexibility and training history. Independence of observations, normality, linearity and homoscedasticity assumptions of linear regression were met.

Total saddle height was calculated as the sum of the measured saddle height and the crank length. The individual configuration of each participant's bicycle was analysed as a relative value as follows:

- Total saddle height was calculated as a percentage of trochanteric leg length.
- Saddle setback was calculated as a percentage of saddle height.
- Handlebar drop was calculated as a percentage of saddle height.
- Handlebar reach was calculated as a percentage of stature.

All bicycle configuration measurements, joint kinematics, anthropometrics, flexibility and training data are expressed as means and standard deviation (*mean* ± *SD*). The statistical analyses were performed using the Tidyr package[39] using R Statistical Software (version February 1, 1335, R Foundation for Statistical Computing, Vienna, Austria).

## Results

The *mean* ± *SD* values of the participants for bicycle configuration, joint angles, flexibility results and training history are shown in Table 3.

A multivariate linear regression was calculated to predict saddle height based on leg length, hamstring flexibility (as determined by the KEA test), spinal flexibility (as determined by the Fingertip to Floor and modified Schober tests), training history and training load. A significant regression equation was found ($F(6,27) = 5.78$), with an adjusted $R^2$ of 0.46. Leg length ($p < 0.01$), KEA test ($p < 0.01$) and mSchober ($p = 0.04$) were significant predictors of saddle height. Saddle height is predicted to increase 0.39 cm for each cm increase in leg length, 0.08 cm for every degree of KEA achieved, and 0.6 cm for every extra cm achieved in the mSchober test (see Fig. 1).

A multivariate linear regression was calculated to predict saddle setback based on leg length, hamstring flexibility, spinal flexibility, training history and training load. A non-significant regression equation

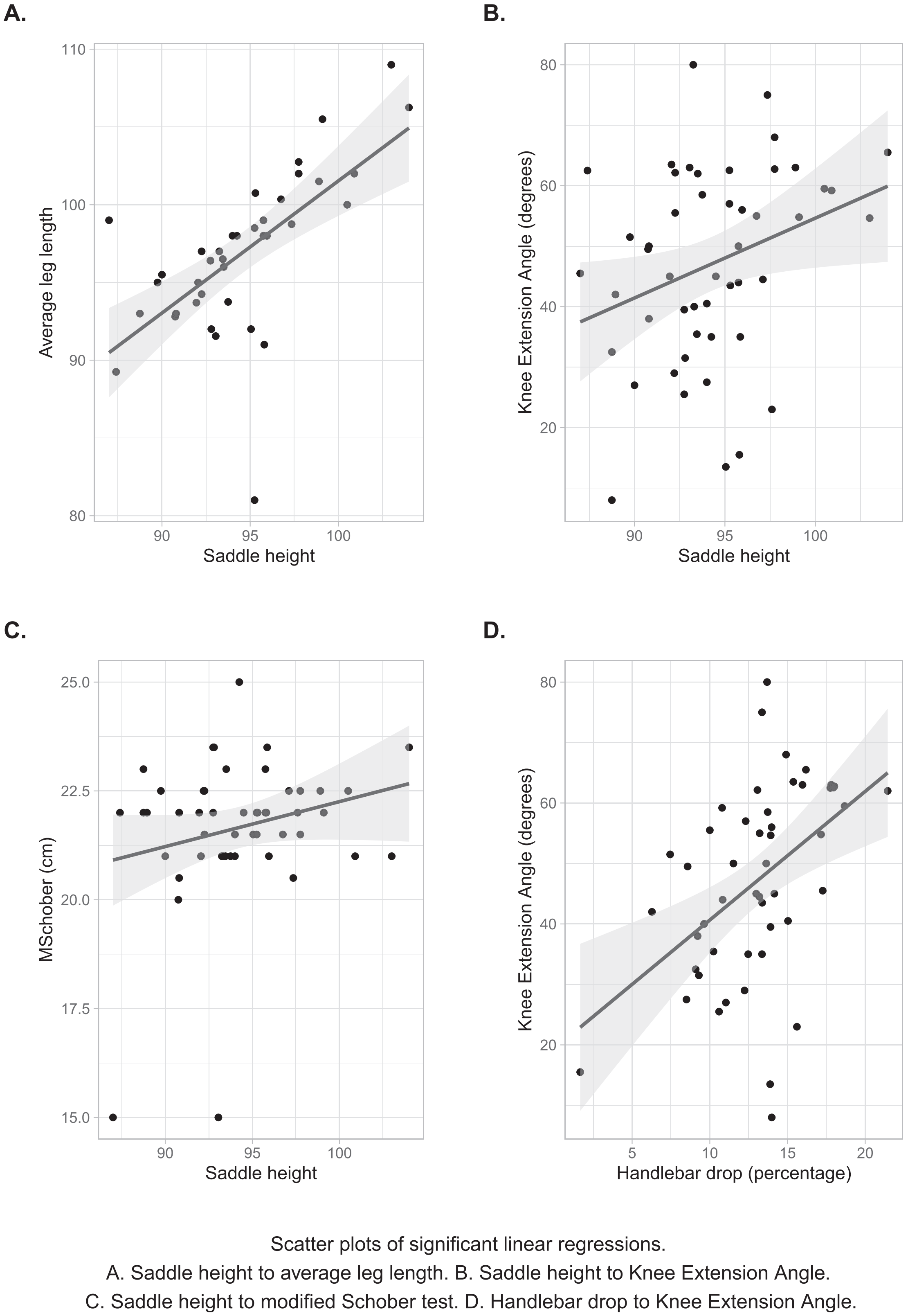

**Fig. 1.** Scatter plots of significant linear regressions. A. Saddle height to average leg length. B. Saddle height to Knee Extension Angle. C. Saddle height to modified Schober test. D. Handlebar drop to Knee Extension Angle.

was found $F(6, 27) = 1.39$, with an adjusted $R^2$ of 0.07.

A multivariate linear regression was calculated to predict handlebar reach based on arm length, hamstring flexibility, spinal flexibility, training history and training load. A non-significant regression equation was found $F(6, 35) = 0.40$, with an adjusted $R^2 = -0.10$.

A multivariate linear regression was calculated to predict handlebar drop based on arm length, hamstring flexibility, spinal flexibility, training history and training load. A significant regression equation was found $F(6,35) = 3.26$, with an adjusted $R^2 = 0.25$. KEA test was a significant predictor of handlebar drop ($p = 0.01$). Handlebar drop was predicted to increase 0.09% for every degree of KEA achieved (See Fig. 1).

## Discussion

The purpose of this study was to determine the relationship between intrinsic factors and freely chosen bicycle configuration. Hamstring flexibility was a key determinant for both saddle height and handlebar drop. Trochanteric leg length and spinal flexibility were also determinants for saddle height configuration.

### *Anthropometrics, flexibility and bicycle configuration*

As expected, we demonstrated that leg length was a good predictor of saddle height. This is in keeping with previous recommendations of measuring saddle height as a percentage of leg length.[12,40,41] With the pelvis stabilised on the saddle and the foot clipped in at the pedals, the hip, knee and ankle must flex and extend through the pedal revolution. A longer leg length allows for a higher saddle height, whilst still having adequate hamstring flexibility in order to reach the pedals. The hamstring muscles are placed on a stretch when the hip is flexed and the knee extends, typical of the position during a pedal revolution. In this study, cyclists with greater hamstring flexibility self-selected a higher saddle height, supporting our hypothesis. Coinciding with our results, previous research has demonstrated that cyclists tend to select saddle heights according to their hamstring flexibility[22] and cyclists with limited hamstring flexibility tended to select lower saddle heights.[21]

Lumbar spine flexibility, as measured with the modified Schober test, was also a predictor for a greater saddle height. Hamstring flexibility allows for more lumbar flexion range and anterior pelvic tilt.[25] As the cyclist leans forward to place his hands onto the handlebars, the lumbar spine needs to flex and the pelvis needs to rotate anteriorly.[27] This anterior rotation allows the cyclist to adopt a greater handlebar drop position, which is a preferable aerodynamic position.[27] Combined with a higher saddle height, which places the handlebars in a relatively lower position, this positions the cyclist in a powerful aerodynamic position.[42] It is known that a higher saddle height is better for performance[8] and this may be linked to our findings that hamstring flexibility is a factor for a greater handlebar drop position. Previous research has also demonstrated that increased hamstring flexibility and a lower handlebar position was associated with improved performance.[43]

Although not scientifically validated, in his book, Andy Pruitt recommends taking into consideration hamstring and lower back flexibility when determining handlebar reach.[20] Greater lumbar flexion was demonstrated when handlebar reach was further away.[27,44] Despite our hypothesis that spinal flexibility would be a predictor for handlebar reach and handlebar drop, we did not find any evidence to support this.

Previous reports have suggested that a more experienced cyclist will adopt a lower handlebar drop position,[15] and that a fairly new cyclist to the sport would cycle in a more upright position.[2] The difference in pedaling technique between different competitive levels of cyclists was dependent on training history and level of experience, but not bicycle configuration, anthropometrics nor training load.[32] We demonstrated no relationship between history of cycling participation and bicycle configuration, albeit none of our cyclists were new to the sport, all having cycled consistently for greater than 18 months. Similarly, there were no significant findings between training load and freely chosen bicycle configuration.

### *Freely chosen bicycle configuration and joint angles*

Freely chosen bicycle configuration resulted in a mean KFA of 36° ± 7°. This is similar to the findings of Dahlquist et al.[34] who demonstrated a mean KFA of 34° despite the fact that more than 50% of their participants had undergone a professional bike fit. Cyclists tend to opt for a range of KFA similar to the recommended range of 25° to 35° [6] with some cyclists selecting a lower saddle height than recommended, which may be related to comfort.[7,45] It should be taken into consideration that the KFA was measured in a natural riding position, not with the pedal horizontal as recommended by Holmes, Pruitt and Whalen.[4] These values may therefore conform more closely to those measured using dynamic methods, as it has been demonstrated that a change from static (using the Holmes method) to the dynamic measurement of KFA differs by approximately 8°.[10,46,47] Our mean KFA of 36° may therefore correlate to approximately 28° using the Holme's method and falls close to the original recommendations of 25° to 35° for optimal performance and injury prevention.[4]

In addition, we found that saddle height and crank length equated to 95%–99% of trochanteric leg length with a mean value of 97%. This compares favourably with the findings that a saddle height set at 100% of trochanteric is most economical.[41] Fitters may therefore be able to utilise a reference range of 95%–99% of trochanteric leg length to set the initial saddle height when an existing reference is not available (new entrants to the sport or previous bicycle is not available for reference). In this way, they can achieve a saddle height that is relatively close to that which has been shown to be optimal for metabolic efficiency. However, factors such as hamstring flexibility may not allow them to achieve a value of 100%. More sophisticated methods should be used to achieve the optimal position based on stability, comfort, economy and other factors.

There are limited recommendations for an optimal hip flexion angle. Previous studies have determined hip flexion angle as a line bisecting the length of the femur and a line horizontal to the floor[48–50] or as an angle bisecting the length of the femur and a line from the hip joint centre to the glenohumeral joint centre.[51] These measures exclude the spinal segments and do not measure the hip joint independently (long axis of femur and lumbar spine-sacrum). We reported a static hip flexion angle of 77° ±5°. Our results are the first reported data for a true hip joint position and from these results, we recommend that hip flexion be determined with the measured leg at top centre pedal position, and as an angle from the length of the femur bisecting a line parallel to the lower lumbar spine and sacrum.

Similar to the hip, the shoulder angle is often simplistically determined as an angle between the elbow, acromion and hip joint centre. A clinical shoulder angle will use the thoracic spine as a reference point, as was done in this study. Our results are the first reported data for a true shoulder joint position, with a static shoulder angle of 112° ±7°. It should be determined whether these hip and shoulder angles represent the optimal range by performing further research.

The mean elbow flexion angle of 19.8° is similar to previous recommendations (Table 2). The mean ankle flexion angle of 116° ±7° is more plantarflexed than previous recommendations (Table 2), however, this may be due to the natural riding position that was adopted for measurement.

This study is not without limitations. Firstly, despite cyclists being comfortable on their bicycles, their individual configuration may not be regarded as being optimal in terms of power and injury prevention. Secondly, the results yielded low $R^2$ values. This indicates that, although significant, we cannot determine exact predictions based on the measured variables alone. As with prior research, bicycle configuration is not an exact science and there are many factors that need to be considered. The definition of "optimal" will depend on each cyclist and what they wish to obtain from fitting: comfort, performance or injury prevention.

## Conclusion

The results of this study provide further recommendations to improve bicycle fitting. Handlebar reach should primarily be determined based on stature and comfort, and that saddle height should take into account trochanteric leg length and lumbar and hamstring flexibility. Hamstring flexibility should also be taken into account when setting handlebar drop.

Our recommendation is that bicycle fitting be performed by initially taking into account leg length and hamstring flexibility. We have observed self-selected joint ranges from a large sample of cyclists and recommend that the cyclist position be improved by positioning the contact points until the major joints coincide with the ranges measured in this study. Further optimising can subsequently be performed using more elaborate methods such as saddle pressure mapping or dynamic kinematics. Reported comfort should also be a key determinate of the final position. As a result of prior findings and our data, we can infer that a cyclist who wishes to adopt a more aerodynamic position with an increased handlebar drop should aim to improve their hamstring flexibility in order to comfortably maintain this position.

## Ethical approval

The study was approved by the Human Research Ethics Committee of the Faculty of Health Sciences of the University of Cape Town (648/2014), and conformed to the principles of the World Medical Association Declaration of Helsinki.[37] Prior to testing, each participant was informed of the risks and stresses associated with participation in the research trial, completed a Physical Activity Readiness Questionnaire (PAR-Q)[36] and signed an informed consent form.

## Submission statement

We confirm that this work is original and has not been published elsewhere, nor is currently under consideration for publication elsewhere.

## Authors' Contribution

This original study proposal was drafted by Wendy Holliday and Jeroen Swart. The data was collected and analyzed by Wendy Holliday with the assistance of Jeroen Swart. This manuscript was written by Wendy Holliday with the valued guidance of Jeroen Swart.

## Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smhs.2021.02.007.

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