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Original research

The effects of relative cycling intensity on saddle pressure indexes

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ABSTRACT

Objectives: To compare pressure load and distribution in various saddle zones through a range of workloads in order to provide clinicians and bike fitters with a better understanding of how to optimise saddle positioning.
Design: Experimental, quantitative study.
Methods: Saddle pressure of seventeen male well-trained cyclists was recorded at 60, 80 and 90% of maximal heart rate, based on data collected during a peak power output test.
Results: Loaded area increased significantly and progressively with increased workload while mean pressure did not change significantly. Point of load indexes in longitudinal and transverse planes both increased significantly and progressively with increases in workload. Distribution of load did not change with intensity.
Conclusions: Saddle pressure mapping should ideally be performed at an intensity similar to that which the cyclist will encounter during the majority of their training and racing. Comparative measurements of saddle pressures should also standardise workload intensity to ensure reliability of these measurements.

Practical implications

Guidelines for optimal saddle choice should take into account the training discipline and the intended riding intensity of the cyclist, such as for recovery, endurance, tempo, threshold and superthreshold.

Cyclists should adopt a natural riding position for saddle pressure mapping during bike fitting.

For cyclists who are interested in training or racing at high intensities, we recommend that assessments be conducted at 80% of MHR or a similar standardised intensity to better replicate the forces produced during high intensity cycling and racing.

1. Introduction

The saddle is one of three contact points between the cyclist and the bicycle. A cyclist will make contact with the saddle at the ischial tuberosities and the pubic rami, which differ in shape and width from person to person. Due to this individual variation, large commercial companies have conducted studies to try and improve saddle comfort and reduce saddle-related pathologies (for example ©Specialized Bicycle Components). However, the extent of the body weight and thus pressure being transferred through each anatomical point depends on the cyclists' individual riding position and the anterior-posterior rotation angle of the pelvis on the saddle.[1]

With advances in technology we are now able to measure the pressure at the interface between the cyclist and the saddle. The reliability and validity of bicycle seat interface pressure measurements has previously been studied.[2] The saddle was divided into three sections to differentiate anterior, posterior left and posterior right. It was concluded that the within trial reliability is excellent for both mean and peak pressure values. The between trial saddle pressures demonstrate moderate to excellent reliability for all areas of the saddle, except the anterior saddle pressure, which demonstrates poor reliability. However, errors may arise from lack of conformity between the saddle contours and the pressure mat, yet these are minimal.

Differences in saddle pressure indexes at varying workloads were also investigated in 22 cyclists who rode at 100 W and then 200 W on one standard saddle.[3] The saddle was divided into five regions for analysis; total saddle, anterior, posterior, posterior left and posterior right regions. The vertical force and medio-lateral forces were both significantly reduced at 200 W compared to 100 W. Maximum pressure in the posterior region also significantly decreased with increasing workload. The forward position of the anterior centre of pressure and the mediolateral width of the posterior centre of pressures were both greater at the higher workload. The reduction in pressure at the higher workload was suggested to

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be as a result of the increased force applied to the pedals and transmitted through to the pelvis with the increase in power, which would reduce load on the saddle. This is similar to the findings by Bressel and Cronin[2] who demonstrated a 39% reduction in pressure on the saddle at 300 W compared to 118 W. However, both these studies were conducted with the cyclist in a position they were not accustomed to (i.e. the bicycle configuration was not set at their freely-chosen position). This may have had an impact on the results, as they may have shifted forwards or backwards on the saddle to obtain a more comfortable riding position.

More recently the effects of workload on saddle pressure between two different saddles has been investigated.[4] Eleven male and eleven female recreational cyclists volunteered for the study and rode at two different workloads, 150 W and 300 W, on two different saddle designs; one standard flat-surfaced saddle and one cutout saddle with a full-centre recess and a hole through the nose. The saddle design had little effect on the seat pressure, however there was a statistically significant increase in mean saddle pressure with the increase in pedaling workload. They postulated that the increased saddle pressure in different workloads may be due to the applied force to the pedals to gain forward propulsion. However, a limitation of this study was the saddle pressure system, as it did not give specific pressures for the anterior, posterior, left or right zones of the saddle, and they recommended that further research be done investigating a range of workloads to compare pressure load and distribution in the various saddle zones. The American College of Sports Medicine[5] has described using heart rate ranges as a method for training intensity. During a race, a cyclists' heartrate intensity will vary according to the topographical profile of the race and overall distance.[6] The cyclist will spend only a fraction of the race or training at absolute fatigue and/or maximal effort greater than 90% heartrate intensity, with the majority of the ride shifting between 60–80% heartrate intensity.[7,8] Investigating this range of heart rate workloads may provide clinicians and bike fitters with a better understanding on how best to optimise saddle positioning for cyclists individual training or racing intensity.

The aim of this study was therefore to assess the change in saddle pressure indexes during three different intensities, namely 60, 80 and 90% of maximum heart rate. It was hypothesised that the mean saddle pressure as well as the area of loading would increase with the increase in intensity.

2. Methods

Seventeen well-trained male road cyclists (27.6 ± 6.7 years, 75.5 ± 8.3 kg, 181.9 ± 4.5 cm, PPO 5.3 ± 0.8 W kg^{-1}) conforming to Level 2 or greater,[9] were recruited for this study. Prior to testing each participant was informed of the risks and stresses associated with participation in the research trial, were personally interviewed about their training history, completed a Physical Activity Readiness Questionnaire (PAR-Q)[10] 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, and conformed to the principles of the World Medical Association Declaration of Helsinki.[11]

The participants reported to the laboratory on two separate occasions with their own bicycle and cycling shoes. The participants' bicycle was loaded onto a Wahoo Kickr Smart Trainer (Wahoo Fitness©, 2018) and they rode in their own freely chosen bicycle configuration.

On the first visit to the laboratory the participant's anthropometrics were taken, followed by an incremental exercise test to volitional exhaustion. The participants performed a standard warm-up and after a three minute rest period completed a Peak Power Output (PPO) and Peak Oxygen Consumption test to determine the required heart rate for the experimental trials. 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 rpm. PPO was calculated by averaging the power output for the final minute of the VO_{2peak} test. VO_{2peak} was recorded as the highest VO^2 reading recorded for 30 s during the test. Maximal heart rate (MHR) was recorded as the highest heart rate achieved during the incremental exercise test.

On the second visit to the laboratory, each participants' bicycle was loaded onto a Wahoo Kickr Smart Trainer (Wahoo Fitness©, 2018) and a standard saddle was fitted to their bicycle, ensuring that saddle height and setback remained the same. A standard saddle (Fabric® Scoop Elite Shallow, 142 mm) was used for all participants to reliably compare the data as previously recommended.[2] The saddle pressure mapping mat (Gebiomized®) was placed on the saddle by the same investigator to ensure repeatability of the positioning throughout the trial.

Each participant performed a standardised warm-up followed by a fifteen minute exercise trial at three different workload intensities based on the Lamberts Submaximal Cycle Test,[12] which proved to be highly reliable. The intensity was set at 60% of their individual MHR recorded during the VO_2 max test, for the first six minutes, immediately followed by six minutes at 80% MHR and a further three minutes at 90% MHR. Resistance was increased via the Wahoo Fitness app (v5.13.3) until the desired heartrate was achieved. The saddle pressure mapping was recorded for the final ten seconds during the last minute of each stage, with the participants' hands on the hoods and seated. Participants were requested to maintain a cadence as close to 90 rpm as possible throughout the trial. Participants were not informed when the saddle pressure mapping data was to be recorded, so as to prevent them changing their pedaling action.

A saddle pressure mapping system (GebioMized®) was used for all testing. The system comprises a thin flexible mat containing 64 sensors, which was fitted over the saddle. The pressure mat was calibrated as per manufacturer instructions. The data collected was transmitted wirelessly to the manufacture software which was installed on a standard Windows computer.

The GebioMized system generates a report on the following:

- Mean pressure; defined as the average instantaneous peak of the maximum pressure recorded at each sensor in each area
- Loaded area for the anterior pubic bone, rear left sit bone and rear right sit bone zones (Fig. 1)
- Absolute maximum of force; defined as the maximum instantaneous peak force
- Mean of total force; sum of forces recorded by each sensor divided by the number of sensors
- Longitudinal (front to back) and transverse (left to right) mean movement of the centre of pressure (CoP), also known as the point of load incidence (Fig. 1)

The system classifies the cyclists sitting position as either Front or Rear and determines a regression line angle, indicating pelvis orientation.

Dynamic saddle pressure mapping data was recorded for the final ten seconds during the last minute of each interval. Specifically at 5, 11 and 14 min. The data was analysed using the manufacturer software. All mean pressure measurements were normalised to body weight.

All data are expressed as means ± standard deviation (mean ± SD). Analysed variables were statistically tested using a one-way ANOVA with repeated measures. When significant main

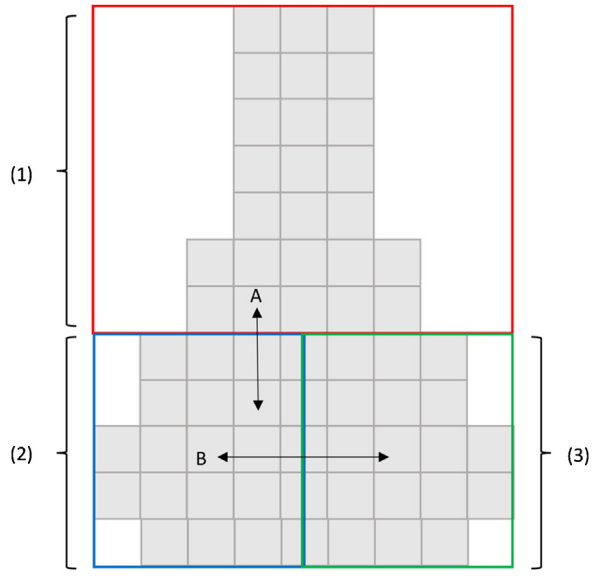

Fig. 1. Pressure mat showing anterior pubic bone (1), rear left sit bone (2) and rear right sit bone (3) zones. Longitudinal (A) and transverse (B) movement of the centre of pressure. Each square depicts a pressure sensor.

effects were found, a Tukey test was used for post-hoc analysis. Significance was accepted when p-value <0.05. The statistical analyses were performed using GraphPad Prism v7.0a (GraphPad Software, San Diego, CA, USA).

3. Results

There were significant changes in the loaded area of the pubic bone zone with an increase in intensity, with changes in means from 5058.82 ± 1323.49 mm^2 at 60%, 5247.06 ± 1278.03 at 80% and 5445.59 ± 1233.97 at 90%, F(1.56, 21.8) = 6.62, p-value = 0.01. There were significant changes in the loaded area of the left sit bone zone, F(1.85, 29.65) = 20.80, p-value <0.01, and right sit bone zone, F(1.33, 21.24) = 6.18, p-value = 0.01. The left sit bone zone demonstrated significant changes between all three intensities, with an increase in mean from 4905.88 ± 994.38mm^2 at 60%, 5325.00 ± 902.04 at 80% and 5630.88 ± 764.93 at 90%. The right sit bone zone demonstrated significant changes between 60% (5195.59 ± 1013.40) and 90% (5604.41 ± 1092.81) only (Table 1 and Fig. 2).

The total loaded area as a percentage of the total area demonstrated a significant increase between all intensities, from 42.71 ± 9.47% at 60%, 46.06 ± 4.99 at 80% and 47.76 ± 4.25 at 90%, F(1.59, 23.88) = 22.64 and p-value <0.01 (Table 1 and Fig. 2).

The movement of the CoP, along the longitudinal and transverse axes, increased significantly. The longitudinal axis demonstrated a significant change between 60% (21.82 ± 7.41 mm) and 80% (30.18 ± 9.46 mm) and between 60% and 90% (36.00 ± 13.96 mm) intensity, F(1.43, 22.94) = 18.78, p-value <0.0001. The transverse axis demonstrated a significant change between all three intensities, increasing from 19.18 ± 7.41 mm at 60%, 33.65 ± 12.84 at 80% and 43.06 ± 18.19 at 90%, F(1.51, 24.16) = 39.17, p-value <0.0001 (Table 1 and Fig. 2).

There were no significant changes in mean pressure for the pubic bone zone nor the rear left and right sit bone zones. Similarly there were no significant changes in absolute maximum of force and front or rear pressure distribution. The mean of total force demonstrated a significant decrease between all three intensities, from 463.47 ± 97.20 N at 60%, 407.94 ± 106.29 at 80% and 380.00 ± 107.56 at 90%, F(1.66, 26.02) = 26.02, p-value <0.01 (Table 1 and Fig. 2).

Table 1
Mean ± SD of pressure mapping variables.

Mean ± SD					
Variables		60%	80%	90%	p-Value
Mean pressure (normalised to body weight) (mbar)	Pubic bone	251.71 ± 114.75 (3.32 ± 1.43)	257.41 ± 121.85 (3.38 ± 1.47)	253.76 ± 123.14 (3.34 ± 1.48)	p = 0.93
	Sit bone (L)	237.94 ± 48.42 (3.18 ± 0.67)	241.24 ± 58.78 (3.22 ± 0.77)	241.71 ± 59.27 (3.21 ± 0.74)	p = 0.91
	Sit bone (R)	257.76 ± 69.10 (3.46 ± 1.04)	244.35 ± 69.08 (3.27 ± 1.00)	252.41 ± 56.96 (3.37 ± 0.79)	p = 0.36
Loaded area (mm^2)	Pubic bone	5058.82 ± 1323.49	5247.06 ± 1278.03	5445.59 ± 1233.97	p = 0.01[b]
	Sit bone (L)	4905.88 ± 994.38	5325.00 ± 902.04	5630.88 ± 764.93	p < 0.001[a,b,c]
	Sit bone (R)	5195.59 ± 1013.40	5476.47 ± 1081.32	5604.41 ± 1092.81	p = 0.01[b]
Absolute maximum of force (N)		595.53 ± 125.61	574.00 ± 129.27	563.29 ± 128.69	p = 0.30
Mean of total force (N)		463.47 ± 97.20	407.94 ± 106.29	380.00 ± 107.56	p<0.001[a,b,c]
Loaded area/total area (%)		42.71 ± 9.47	46.06 ± 4.99	47.76 ± 4.25	p<0.001[a,b,c]
Area of pressure (%)	Front	47.94 ± 15.47	49.06 ± 15.94	48.65 ± 15.00	p = 0.74
	Rear	52.06 ± 15.47	50.94 ± 15.94	51.35 ± 15.00	p = 0.74
Point of load incidence (mm)	Longitudinal axis	21.82 ± 7.41	30.18 ± 9.46	36.00 ± 13.96	p<0.001[a,b]
	Transverse axis	19.18 ± 7.41	33.65 ± 12.84	43.06 ± 18.19	p<0.001[a,b,c]

[a] Significant change between 60 and 80% maximum heart rate (MHR).
[b] Significant change from 60% to 90% MHR.
[c] Significant change between 80 and 90% MHR.

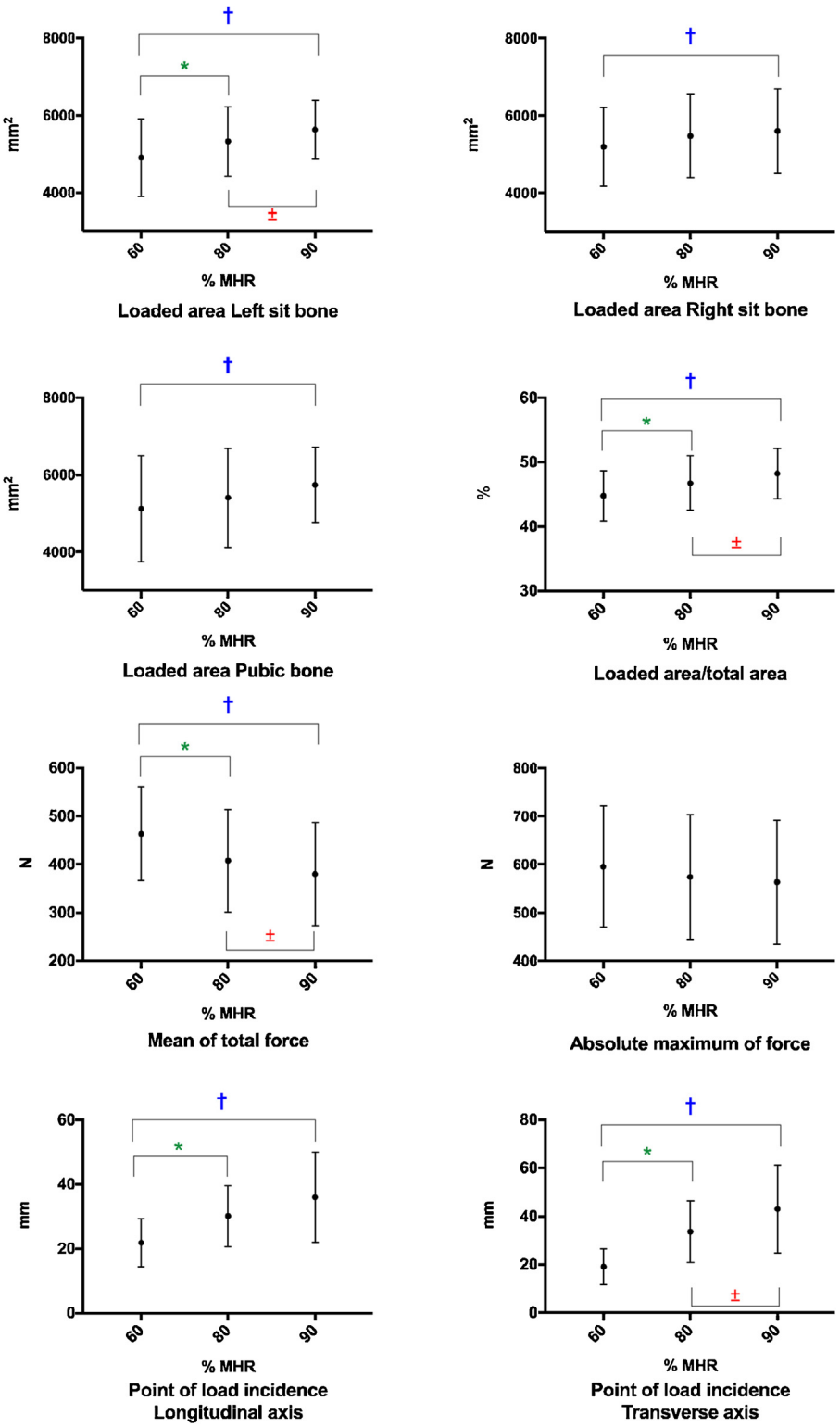

Fig. 2. Loaded area Left and Right sit bone, Pubic bone and Point of load incidence, Longitudinal and Transverse axis, Mean of total force and Absolute maximum of force. *Significant difference between 60% and 80%, †significant difference between 60% to 90%, and ±significant difference between 80% and 90% maximum heart rate (MHR).

4. Discussion

The purpose of this study was to assess the interaction between the cyclist and the saddle during three different cycling intensities. We observed a progressive increase of the loaded area with increasing intensity and this occurred in all three of the saddle zones. In addition, there was a decrease in mean total force with increasing intensity and an increase in CoP movement with increasing intensity.

Mean pressure remained unchanged. This variable is the mean of the instantaneous peak pressures recorded for sensors in each area. This may be confused with the mean pressure over time. Researchers and practitioners should be aware of this definition to avoid incorrect interpretation of the outcome values.

In contrast to our findings, Carpes et al.,[4] demonstrated an increase in saddle pressure between two different workloads, 150 W and 300 W. However these participants were instructed to maintain their trunk angle at 60°, with the researchers ensuring this position was kept constant during the trials. It is possible that this intervention may have altered the relative distribution of pressure on the saddle. It has previously been demonstrated that as intensity increases, riders naturally flex the thoracic and lumbar spine and flex the elbow joint while maintaining the kinematics of the hip and shoulder joint (*Unpublished results, in review*). In contrast, in our study the participants were allowed to adopt their freely chosen posture. Previously Bini et al.,[13] demonstrated no change in pelvic anterior-posterior rotation with an increase in intensity, and our data confirms this as the relative distribution of pressure (front and rear) on the saddle did not alter significantly. However as intensity increases there is a progressively larger loaded area in contact with the saddle.

Two studies have paradoxically demonstrated a reduction in pressure with an increase in workload. Mean and peak pressures were greater at 118 W compared to 300 W when riding with the hands holding on the top of the handlebars.[2] Likewise, total, anterior and posterior maximum pressure all decreased at 200 W compared to 100 W, with an increase in anterior and medio-lateral CoP movement.[3] As the power increased to 200 W, the vertical force on the saddle decreased. The authors postulated that a greater power output would necessitate a greater force application at the pedals. As this force is mediated primarily through hip and knee extension it would act to reduce the load on the saddle. This is confirmed by our findings that there was a significant decrease in mean force with an increase in intensity.

The movement of the CoP (also known as the point of load incidence), in both the longitudinal and transverse planes, increased progressively with intensity. This is in keeping with the previous findings by Potter et al.[3] This is a measure of stability and is used in clinical practice to assess the stability of the rider position when adapting the bike fit parameters. Natural pelvic roll from side to side has been demonstrated to occur in cycling.[14,15] This pelvic rocking can be exaggerated at higher speeds[14] and our results indicate that this pelvic rocking increases at higher workloads independent of cadence, which remained unaltered. As both transverse and longitudinal movements increase with increasing workload any comparative measurements when adapting contact point position should be compared at the same relative workload intensity.

5. Conclusion

The contact area between the cyclist and the saddle and the CoP movement increases with intensity while total saddle force decreases. Although the hand position should be standardised, the cyclist should be allowed to adopt a natural riding position when comparing saddle pressure measurements after altering contact point position or when measuring pressure using different saddle designs.

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