Gender Differences in Bicycle Saddle Pressure Distribution during Seated Cycling

JAMES J. POTTER[1], JULIE L. SAUER[1], CHRISTINE L. WEISSHAAR[1], DARRYL G. THELEN[1,2,3], and HEIDI-LYNN PLOEG[1,2]

[1]*Departments of Biomedical Engineering;* [2]*Mechanical Engineering; and* [3]*Orthopedics and Rehabilitation, University of Wisconsin-Madison, Madison, WI*

ABSTRACT

POTTER, J. J., J. L. SAUER, C. L. WEISSHAAR, D. G. THELEN, and H.-L. PLOEG. Gender Differences in Bicycle Saddle Pressure Distribution during Seated Cycling. *Med. Sci. Sports Exerc.*, Vol. 40, No. 6, pp. 1126–1134, 2008. **Introduction:** The purpose of this study was to investigate the influence of gender, power, hand position, and ischial tuberosity (IT) width on saddle pressure during seated stationary cycling. **Methods:** Twenty-two experienced cyclists (11 males and 11 females) were fitted to an adjustable stationary bicycle and pedaled at 100 and 200 W in both the tops and drops hand positions. An instrumented pressure mat was used to record saddle pressure distribution. Normalized force, maximum sensor pressure, and center of pressure were computed for anterior and posterior regions of the saddle. **Results:** When increasing power from 100 to 200 W, there were significant reductions in normalized force in all saddle regions and maximum pressure in the posterior region. When moving from the tops to drops hand position, centers of pressure in all regions moved forward, normalized force and maximum pressure on the posterior region decreased, and females (but not males) exhibited an increase in normalized force and maximum pressure in the anterior region. Male centers of pressure were farther forward in the anterior and total saddle regions than they were for females. Females exhibited a larger IT width than males. Inter-individual differences in IT width were significantly correlated with the posterior center of pressure fore-aft location on the saddle in the tops and drops hand positions and with the width between the posterior left and right centers of pressure in the tops hand position. **Conclusions:** There are significant gender-related differences in saddle loading which are important to consider when designing saddles. These differences are especially important when riders are in the handlebar drops and more weight is supported on the anterior pelvic structures. **Key Words:** SADDLE DESIGN, BICYCLE FITTING, DYNAMIC LOADING, ISCHIAL TUBEROSITY WIDTH

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Discomfort with sitting on a bicycle saddle for extended periods of time remains one of the most common complaints among cyclists. The loading imposed on the soft tissues has been associated with troublesome ailments such as numbness (5,18), nodules (10), chafing, erectile dysfunction (6,7,16,17,19), and traumatic urethritis (21). For these reasons, bicycle saddle designs have evolved in an effort to improve comfort and reduce the likelihood of saddle-related pathologies. Various features such as cutouts, custom widths, and variable padding exist among current saddles, with many of these features designated as gender-specific. However, there is limited data in the literature by which to quantitatively design a saddle to accommodate the unique saddle loading patterns associated with male and female riders.

The emergence of pressure-sensitive mats has enabled quantitative investigations of the load distribution on the saddle during seated cycling. Earlier studies showed that the presence of a cut-out can influence pelvic tilt and perceived comfort among female cyclists (4); and that saddles with a partial cut-out or without a nose (8) reduced perineal pressure in male cyclists. In a comparison between genders, Bressel and Cronin (3) showed that a reduction in peak saddle pressure occurs when going from the tops to the drops hand position in males but not in females. It was speculated that gender-related differences in segment mass distributions (i.e., a lower center of mass in females) may have contributed to this finding (3). However, there are other factors which could play a role in gender-specific loading patterns including variations in pelvic geometry, power output, and bicycle fit. For example, if both genders were to sit in the same location on the same saddle, the greater width between ischial tuberosities among females (11) might tend to reduce the loading on the posterior bony structures and enhance the loading in the perineal region. An improved understanding of the spatial and temporal variations in saddle loading coupled with detailed anthropometric measures are important to investigate these issues further.

The primary purpose of this study was to investigate the influence of gender, power, and hand position on saddle

Address for correspondence: Heidi Ploeg, Ph.D., Department of Mechanical Engineering, 1513 University Ave., Madison, WI 53706; E-mail: ploeg@engr.wisc.edu.
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pressure distributions during seated stationary cycling. We hypothesized that anterior saddle pressure would increase with a change of hand position from the tops to the drops and would be linked with ischial tuberosity (IT) width. We also hypothesized that the magnitude of peak saddle loading would be greatest near bottom dead center crank position when pedal forces are lowest (1,9,13) and that peak saddle loads would decrease at larger power outputs when pedal forces are increased (14,20). A secondary purpose was to determine whether measurable differences in pressure distributions could be observed between two noncutout saddles which differ in rear saddle width and depth of cushioning in the pubic arch region.

METHODS

Participants. Twenty-two experienced cyclists (eleven males and eleven females) were recruited from local cycling groups via flyers and posters. Subject characteristics are shown in Table 1. All subjects were at least 18 yr, had been road bicycling for at least 1 yr and were regularly riding at least 3 h·wk^{-1} at the time of the study. Subjects had no history of saddle sores, skin irritations in the perineal area, perineal nodules, or perineal numbness. Participants gave written informed consent in accordance with a protocol approved by the University of Wisconsin's Health Sciences Institutional Review Board.

Procedures and instrumentation. An adjustable stationary bicycle was set up for each subject, using a standardized bike fitting procedure for road racing cyclists (bikefitting.com, The Netherlands). The stationary bicycle was fitted with a saddle marketed as gender-neutral (*saddle A*—Bontrager™ Race X Lite Pro, 2006) and standard drop handlebars (400 mm width, 145 mm drop). In addition to *saddle A*, nine of the 11 female subjects were also tested on *saddle B* (Fi'zi:k™ Vitesse, 2006), which is marketed as female-specific. A bubble level was used to mount the saddle with its top surface horizontal. The posterior edge of the saddle was positioned 10 cm behind the middle of the seat post (Fig. 1). Individualized rider measurements included the following: height, weight, torso height, arm length, inseam length, foot length, shoulder width, bike shoe brand and model, and pedal brand and model. These measures were used to adjust the seat height, seat tube angle, handlebar reach, and handlebar height. After the initial fitting, the bicycle setup for each rider remained constant for the duration of the test.

TABLE 1. Characteristics (mean [SD]) of subjects tested in this study. Despite being smaller in height and mass, females had significantly (*$P < 0.001$) greater IT width than males.

	Male	Female
N	11	11
Height (m)	1.81 (0.07)*	1.69 (0.06)
Age (yr)	36.8 (11.1)	36.7 (10.4)
Mass (kg)	76.3 (5.9)*	62.3 (7.0)
IT width (mm)	114.0 (14.2)	135.3 (10.4)*

For each subject, the distance between the ischial tuberosities was measured using a floral foam block placed on a foot stool positioned next to a wall. Subjects were instructed to place their back flat against the wall and lower themselves onto the foam. Once an initial impression was felt, the subject was asked to pull up on the baseboard to ensure that a deep measurable impression would be made. Ball bearings were then rolled on the foam indentations until they came to rest at the deepest points of the impressions. Width was determined by measuring the distance between the ball bearings with a straight edge ruler. This procedure was performed on two separate foam blocks for each subject, and the widths were averaged.

Pressure distribution was measured with a mat (Fig. 2) containing a matrix of square piezo-capacitive pressure sensors (18.75 mm per side, Bike Saddle Mat; Novel Inc, Munich, Germany). The mat was positioned so that its longitudinal midline was collinear with the saddle midline, and the two posterior-most rows of sensors were hanging off the rear edge of the saddle. Pressure data was collected at 100 Hz from the 90 sensors that contacted the saddle surface.

Four reflective motion capture markers were placed on the crank of the stationary bicycle. Commercial software (EVaRT v. 4.7; Motion Analysis Corp, Santa Rosa, CA) was used to calibrate the motion capture collection volume and record the crank marker kinematics. A triggering pulse was used to synchronize pressure and motion capture data collections.

Subjects warmed up for 5 min on *saddle A* at a self-selected cadence and trainer resistance before data collection. Each subject then performed a series of trials in which power (100 and 200 W) and hand position (tops and drops, Fig. 1) were varied while cadence was maintained at a constant 90 rotations per minute. An instrumented rear hub (PowerTap; Saris Corp, Madison, WI, USA) provided the subject with real-time feedback of cadence and power output. After the subject achieved a steady power output in a specified hand position, pressure distribution and crank kinematics were simultaneously recorded for a minimum of 15 pedal strokes (10 s). Testing on *saddle B* was conducted at 200 W in the tops and drops hand positions.

Data analysis. The crank marker kinematics were low-pass filtered at 5 Hz using a quintic smoothing spline (22) and then used to compute the crank angle at each time step. Each of the pressure sensor trajectories was then interpolated at 100 evenly spaced intervals over the full 360° pedal stroke using piecewise cubic splines. Pressure curves from nine consecutive pedal strokes were averaged for each trial.

A normal vector was found for each sensor location on *saddle A*. This was done by mapping the saddle surface with a laser scanner (ShapeGrabber AI300; ShapeGrabber™ Inc, Ottawa, Canada) and taking cross-sections through the surface at a point in the middle of each sensor using geometric analysis software (Geomagic Studio 8; Raindrop Geomagic™, Inc, Research Triangle Park, NC, USA). Using the normal vector, the force from each sensor

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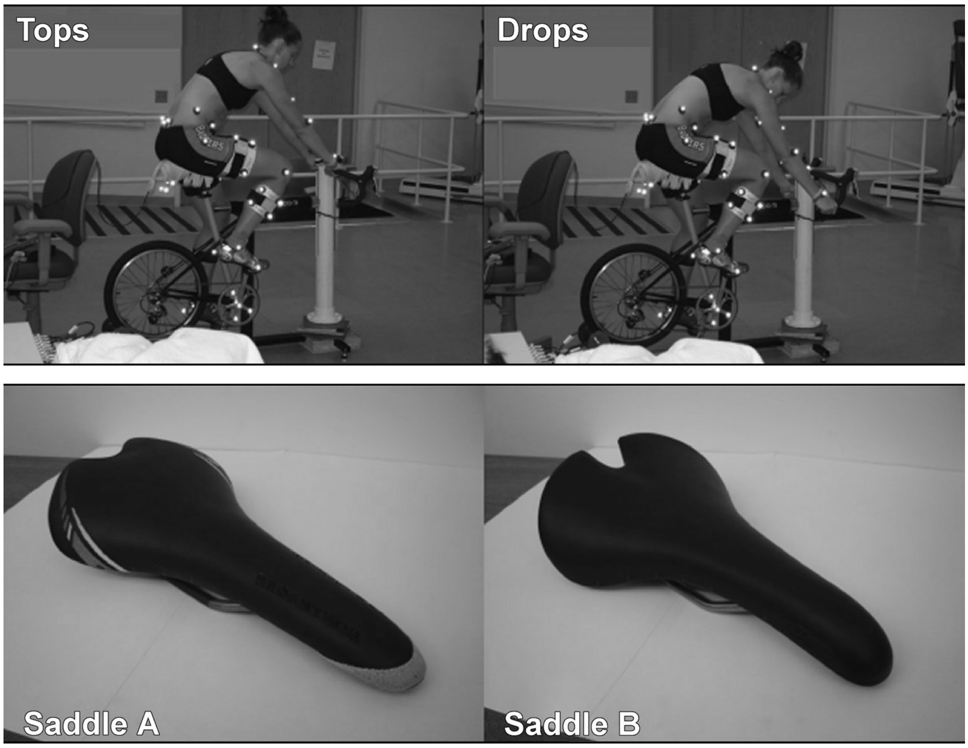

FIGURE 1—Subjects rode in the tops and drops hand positions. All subjects rode on *saddle A* (Bontrager™ Race X-Lite Pro, 2006) and nine of eleven subjects also rode on *saddle B* (Fi'zi:k™ Vitesse, 2006).

could be separated into vertical, anteroposterior (AP), and mediolateral (ML) components (Fig. 3).

The pressure mat was divided into five regions for analysis: total saddle, anterior, posterior, posterior left, and posterior right (Fig. 2). The division between the anterior and posterior halves was made at 93.75 mm from the rear edge. This division represented the inflection point of the curvature of the lateral edge of *saddle A*. The following summary measures of the force, pressure, and center of pressure were computed for each of the areas:

- Normalized vertical and ML force (sum of directional components of sensor force vectors, normalized to subject body weight (BW)—see Fig. 3)
- Normalized maximum pressure (largest average pressure recorded by a single sensor in region, normalized to subject body mass)
- AP center of pressure
- ML center of pressure

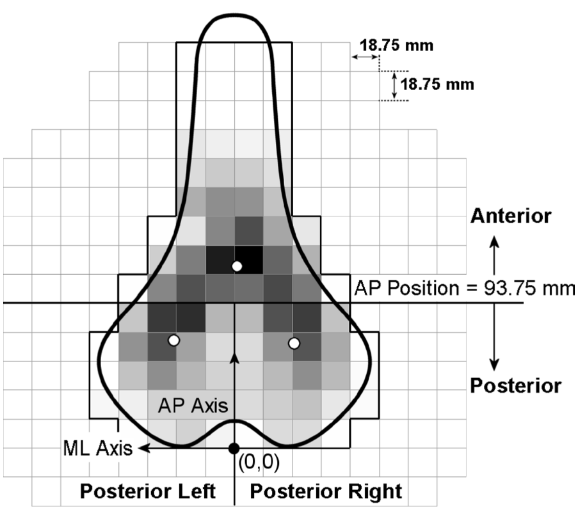

FIGURE 2—Pressure mat configuration on saddle, with saddle regions and origin of sensor coordinate system indicated, and sample pressure distribution with anterior, posterior left, and posterior right centers of pressure shown.

Statistical analysis. A three-way ANOVA test was used to assess the influence of power (100 and 200 W), hand position (tops and drops), and gender (male and

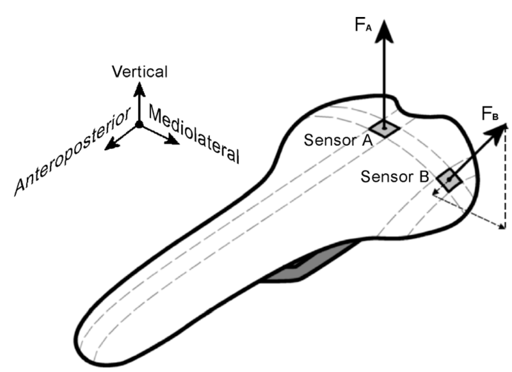

FIGURE 3—Illustration of directional components of force for two hypothetical sensor locations.

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female) on the summary measures, with repeated measures on the power and hand position factors. Tukey HSD *post hoc* test was used to conduct pair-wise comparisons of main effects. The probability associated with Type I error was set at $P = 0.05$ for all observations. The relationship of IT width with pressure and force measures was assessed using Pearson's product-moment correlation coefficient. A paired Student's *t*-test was used to compare normalized maximum pressure between the two saddles.

RESULTS

Vertical and ML forces. The normalized vertical force on the saddle varied substantially throughout a pedal stroke, with much of the variation occurring in the anterior region of the saddle (Fig. 4). Vertical loading oscillated twice per pedal stroke, reaching a peak loading slightly prior to the bottom dead center position of each crank arm (160° crank angle). Minimum saddle loading occurred at 45° into the downstroke of each limb. The net vertical force averaged from 44% to 47% of BW when pedaling at 200 W (Table 2).

The normalized vertical force was significantly ($P < 0.001$) smaller in the drops than in the tops hand position and significantly ($P < 0.013$) smaller at 200 than at 100 W (Table 3). Gender-related differences were observed between the tops and drops hand positions, with the vertical force on the anterior region being significantly ($P < 0.001$) greater in the drops than in the tops for females but not for males. Normalized ML force in the posterior left region of the saddle was significantly ($P < 0.001$) smaller in the drops than in the tops and significantly ($P = 0.013$) smaller at 200 than at 100 W.

Maximum pressure. Normalized maximum pressure in the posterior region significantly ($P < 0.001$) decreased when increasing power from 100 to 200 W and was significantly ($P < 0.001$) greater in the tops hand position than in the drops (Fig. 5). In the anterior region, normalized maximum pressure in males was not different between the tops and drops hand positions, whereas females had significantly ($P < 0.001$) greater maximum pressure in the drops than in the tops. Although not statistically significant ($P = 0.089$), the anterior maximum pressure showed a trend of decreasing at 200 W compared to 100 W for both genders.

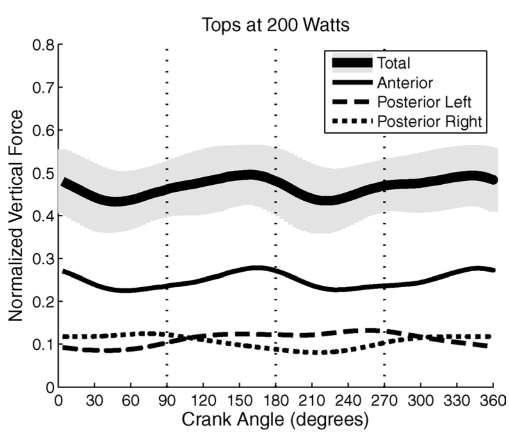

FIGURE 4—Normalized vertical force on the total, anterior, posterior left, and posterior right saddle regions for the tops hand position at 200 W. Right crank is vertically upward at 0°. Shaded area shows ±1 SD of the ensemble average data.

TABLE 2. Summary measures [mean (SD)] of vertical force normalized to BW for the total, anterior, and posterior regions of saddle, and ML force normalized to BW for the posterior left region in the tops and drops hand positions at 100 and 200 W.

	Male		Female	
	Tops	Drops	Tops	Drops
Vertical force/BW (N/N)				
Total saddle				
100 W	0.510 (0.075)	0.477 (0.065)	0.504 (0.047)	0.477 (0.058)
200 W	0.466 (0.080)	0.440 (0.078)	0.463 (0.060)	0.458 (0.067)
Anterior				
100 W	0.293 (0.099)	0.317 (0.080)	0.238 (0.087)	0.292 (0.096)
200 W	0.267 (0.074)	0.296 (0.070)	0.224 (0.096)	0.291 (0.104)
Posterior				
100 W	0.217 (0.081)	0.160 (0.069)	0.267 (0.076)	0.185 (0.069)
200 W	0.199 (0.072)	0.144 (0.059)	0.239 (0.072)	0.167 (0.069)
ML force/BW (N/N)				
Posterior Left				
100 W	0.054 (0.022)	0.039 (0.019)	0.078 (0.027)	0.048 (0.016)
200 W	0.050 (0.021)	0.036 (0.017)	0.069 (0.026)	0.044 (0.015)

Regions of the saddle are defined in Figure 2.

The females who rode *saddle B* exhibited significantly ($P = 0.036$) reduced normalized anterior maximum pressure in the drops hand position compared to riding *saddle A* (an average 32% reduction from 0.79 kPa·kg^{-1} to 0.53 kPa·kg^{-1}). For these riders, there were no significant differences in maximum pressure between saddles in the tops hand position or in the posterior region in the drops hand position.

Center of pressure. The AP location of the total saddle center of pressure oscillated twice per pedal stroke, with its most forward location occurring near the top dead center position of each crank, and most posterior point location being reached slightly past 90° into the downstroke (Fig. 6). This caused the total saddle and anterior centers of pressure to cycle twice per pedal stroke. During the downstroke of each limb, posterior centers of pressure moved forward on the side of the driving limb and backward on the side of the recovery limb.

Mean locations of the anterior, posterior, and total saddle centers of pressure were significantly ($P < 0.01$) farther forward in the drops hand position when compared to the tops (values in Table 4, ANOVA in Table 5). Compared to females, the male centers of pressure were significantly farther forward in the anterior ($P < 0.01$) and total ($P = 0.022$) saddle regions. There were two significant gender-by-hand position interaction effects: females in the tops (compared to the drops) showed an increased ML width between the posterior left and posterior right centers of pressure ($P < 0.001$) and a rearward shift in the posterior region center of pressure ($P < 0.001$). In addition, females tended to have a larger posterior center of pressure width than males in the tops hand position (mean 83.5 versus 79.6 mm at 200 W), but this difference was not statistically significant.

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TABLE 3. Statistical significance of the effects of gender (Gen), power (Pow) and hand position (Hdp) on measures of vertical force and ML force normalized to BW, and maximum pressure normalized to body mass (Mass) for different areas of the saddle (ANOVA, *$P < 0.05$)

	Gen	Pow	Hdp	Gen*Pow	Gen*Hdp	Pow*Hdp	Gen*Pow*Hdp
Vertical force/BW							
Total	0.930	<0.001*	<0.001*	0.370	0.057	<0.001*	0.198
Anterior	0.393	0.011*	<0.001*	0.163	0.022*	0.311	0.636
Posterior	0.248	<0.001*	<0.001*	0.624	0.086	0.320	0.482
ML force/BW							
Posterior left	0.087	0.013*	<0.001*	0.376	0.007*	0.133	0.380
Max pressure/Mass							
Anterior	0.150	0.089	<0.001*	0.583	<0.001*	0.256	0.876
Posterior	0.796	<0.001*	<0.001*	0.909	0.984	0.084	0.858

Tukey HSD Test was used to investigate significant interactions. Regions of the saddle are defined in Figure 2.

At 200 W, the forward position of the anterior center of pressure ($P = 0.001$) and ML width of the posterior centers of pressure ($P = 0.002$) were both greater than at 100 W. The forward position of the posterior center of pressure was greater at 100 W than at 200 W in the tops hand position ($P = 0.004$), but there was no difference in the drops.

Ischial tuberosity (IT) width. The posterior center of pressure width was narrower than IT width for all subjects. Greater IT widths were significantly linked with a more rearward posterior center of pressure in both the tops ($P = 0.003$) and drops ($P = 0.007$) hand positions (Fig. 7a) and were also positively correlated with the distance between

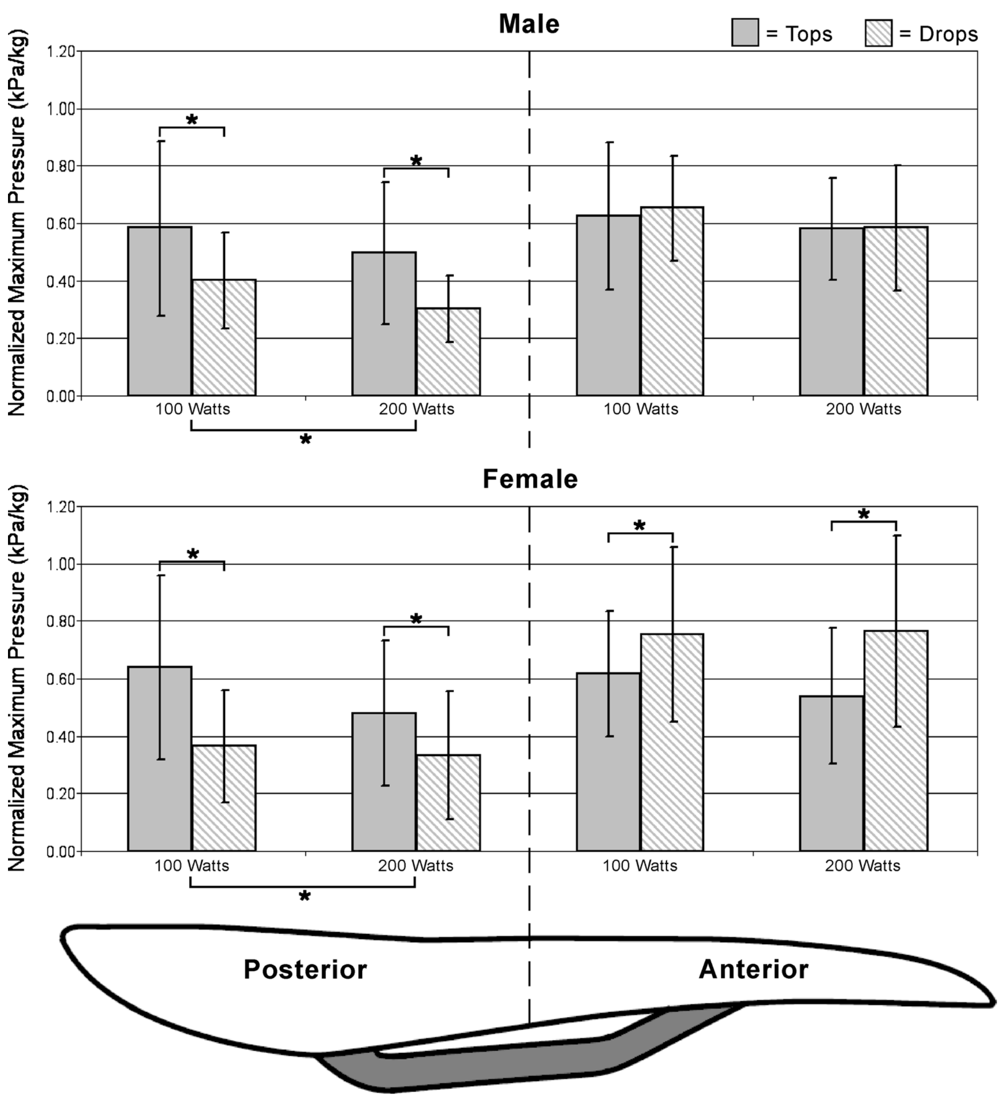

FIGURE 5—Maximum pressure normalized to body mass on the posterior and anterior regions for males (top) and females (bottom) with varying power and hand position. Both females and males experienced a reduction in posterior pressure when switching from the tops to drops hand position, and when increasing from 100 to 200 W. However in the anterior region, only females exhibited a significant increase in pressure when moving to the drops hand position (*$P < 0.001$).

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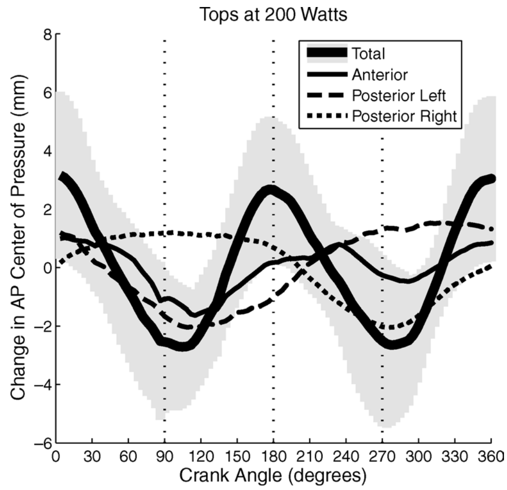

FIGURE 6—AP position of center of pressure relative to mean location for total, anterior, posterior left, and posterior right saddle regions in the tops hand position at 200 W. The net center of pressure oscillates in the fore-aft direction twice per pedal stroke, reaching a peak forward position in the top and bottom dead center crank position (right crank is vertically upward at 0°). Shaded area shows ±1 SD of the ensemble average.

the posterior centers of pressure (P = 0.046) in the tops hand position (Fig. 7b).

DISCUSSION

This study highlights the inter-related effects that crank angle, power output, hand position, and gender have on saddle loading during seated cycling. In particular, we have shown that females exhibited greater changes in anterior force, maximum anterior pressure, and posterior centers of pressure (width and AP location) as a result of switching from the tops to the drops hand position compared to their male counterparts. We have also demonstrated that saddle modifications other than cutouts can influence maximum anterior pressure in females, especially in the drops hand position. Given that many saddle-related pathologies are associated with loading in the perineal region (5,16), this information has substantial relevance for designing saddles that address the cause of these pathologies.

The absolute magnitudes of peak pressure (66 kPa when riding at 100 W) were of similar magnitude to those recorded by Lowe et al. (8) and Bressel and Cronin (3). The effects of gender on peak saddle pressure were also consistent with the results of Bressel and Cronin (3), who showed that females experience less pressure reduction than males when switching from the tops to the drops hand position. It was suggested that this difference may be because of gender-related differences in anthropometry. Specifically, females generally have a lower center-of-mass in the upper body, resulting in a reduced ability to offload weight onto the handle bars in a drops hand position. However, our analysis of typical pressure profiles suggests that differences in the pelvis-saddle interaction may also play an important role. In particular, males often exhibited an anterior region of high pressure, especially when riding in the drops hand position, but the pressure tended to taper off relatively continuously toward the posterior pelvic bones (Fig. 8a). In contrast, females often exhibited a localized anterior pressure spot that was distinct from smaller pressures spots in the posterior saddle region (Fig. 8b). As a result, the anterior saddle was often bearing a substantial proportion of the saddle load in the drops, which likely contributed to the large anterior pressure among females.

The gender-related difference in pressure profiles may arise from fundamental differences in riding style and pelvic geometry. Sauer et al. (15) found that in road cycling postures, and especially in the drops hand position, the pelvis is generally rotated forward to such a degree that weight is likely more supported on the anterior pelvic bones (i.e., under the pubic symphysis and ischiopubic rami, shown in Fig. 9) and less on the ischial tuberosities. Accordingly, we found that the ML width between posterior pressure spots was always smaller than the IT width (for example, 80 mm vs 114 mm for males in the tops hand position). Given that the females had a greater IT width than the males (a result that was consistent with other studies, e.g., (11)), but not a significantly different posterior center of pressure width in the drops, it could be inferred that female riders experienced loading more medial and anterior to the tuberosities than the males. This difference, coupled with slightly greater anterior pelvic tilt among females in a drops handlebar position (15), could underlie our observation that posterior pressure width decreased when switching to a drops hand position among the females but not the males. In addition, the typical female pelvis (Fig. 9b) has a wider and more rounded pubic arch than males, which would position the middle of the ischiopubic rami laterally farther outside the saddle surface, leaving more force to be supported under the pubic symphysis and posterior regions of the ischiopubic rami. The narrower and less rounded pubic arch of males (Fig. 9a) could promote more consistent contact

TABLE 4. Summary measures [mean (SD)] of AP positions of total, anterior and posterior regions relative to rear edge of saddle, and ML width between posterior left and posterior right centers of pressure, in the tops and drops hand positions at 100 and 200 W.

	Male		Female	
	Tops	Drops	Tops	Drops
AP location (mm)				
Total saddle				
100 W	110.7 (15.1)	119.2 (15.5)	93.9 (12.7)	105.2 (13.2)
200 W	111.2 (13.3)	121.5 (14.3)	95.7 (15.0)	108.9 (15.4)
Anterior				
100 W	138.2 (7.4)	141.4 (9.0)	130.1 (5.0)	130.6 (6.0)
200 W	138.9 (7.8)	143.5 (8.9)	132.8 (5.1)	133.9 (7.3)
Posterior				
100 W	69.1 (3.5)	69.6 (4.2)	61.6 (6.7)	64.8 (5.0)
200 W	68.2 (3.8)	69.7 (4.4)	60.5 (6.1)	64.6 (5.1)
ML width (mm)				
Posterior				
100 W	77.8 (6.0)	77.4 (4.8)	82.5 (5.0)	78.2 (5.9)
200 W	79.6 (5.8)	78.8 (4.9)	83.5 (4.0)	79.3 (5.4)

Regions of the saddle are defined in Figure 2.

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TABLE 5. Statistical significance of the effects of gender (Gen), power (Pow) and hand position (Hdp) on AP location of the total, anterior and posterior region centers of pressure, and ML width between the posterior left and posterior right centers of pressure at 200 W. (ANOVA, $*P < 0.05$).

	Gen	Pow	Hdp	Gen*Pow	Gen*Hdp	Pow*Hdp	Gen*Pow*Hdp
AP position							
Total	0.022*	0.076	<0.001*	0.558	0.161	0.106	0.988
Anterior	0.007*	0.001*	0.009*	0.183	0.077	0.096	0.494
Posterior	0.006*	0.028*	<0.001*	0.539	0.012*	0.015*	0.922
ML width							
Posterior	0.261	0.002*	<0.001*	0.487	0.004*	0.780	0.497

Regions of the saddle are defined in Figure 2.

between the saddle and ischiopubic rami, creating a more continuous pressure distribution.

Male centers of pressure for the anterior and total saddle regions were significantly farther forward than for females. This may have been an effect of relative pelvic bone width: females might have moved farther back on the saddle to find a wider part to accommodate generally wider pelvic bones. This effect is consistent with the significant negative correlation between the posterior center of pressure position and IT width (Fig. 7a). IT width was also correlated with the width between the posterior centers of pressure in the tops hand position (Fig. 7b). IT width was measured by having the subjects sit in a flexed hip posture on flat floral foam. Distinct impressions under the tuberosities were attained and the width measurements were consistent with more direct anatomical measures reported in the literature (11). In contrast, the ML pressure width measured on the bicycle was dependent on the interplay between geometries of the pelvis and saddle. In particular, the rear saddle width and curvature can affect where the saddle interfaces with the pelvis, making it possible that riders with differing IT widths could bear weight on the same location on the saddle with different anatomical portions of the pelvis. Thus, IT width may be an important measure to consider in both saddle design and saddle fitting if the goal is to load specific anatomical structures. Improved quantitative measurements of anterior pelvic bony structures, including the pubic arch or ischiopubic rami, may also be useful for the design and fitting of road cycling saddles, especially ones designed for low aerodynamic riding positions. In addition, image-based techniques may facilitate a better understanding of the specific soft tissues and bony structures that are loaded when an individual rider is on a saddle (2).

Normalized vertical force varied in a systematic way with changes in power output and hand position. As the power was increased from 100 to 200 W, normalized vertical force on the saddle decreased—a greater power output would require greater load on the pedals, which would take the load off of other weight-supporting structures such as the handlebars and saddle. Because pressure is force distributed over an area, it is not surprising that total, anterior, and posterior normalized maximum pressures all decreased at 200 W relative to 100 W—force on the saddle was significantly reduced in all regions, so pressure would tend to decrease as well, assuming area remained relatively constant.

In comparison to the tops hand position, normalized force in the drops hand position decreased for the total saddle and posterior saddle regions. In addition, the posterior, anterior, and total centers of pressure moved forward. This was probably because of a forward shift of the center of gravity as the torso was flexed from the tops into the lower and more aerodynamic drops hand position. Because force on the pedals remains relatively the same for a constant power

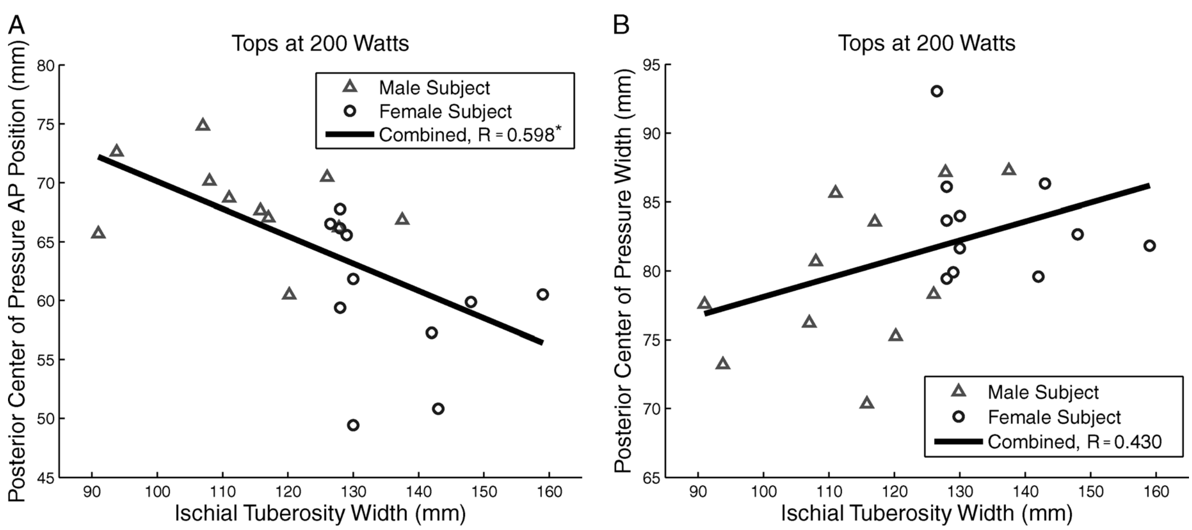

FIGURE 7—Scatter plots of IT width versus posterior center of pressure AP position (a) and ML distance between posterior left and posterior right centers of pressure (b) for all subjects in the tops hand position at 200 W (Pearson correlation, $*P < 0.05$).

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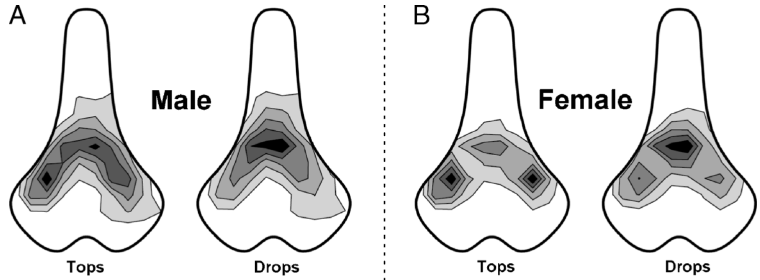

FIGURE 8—Comparison of representative male (a) and female (b) pressure distributions with sensors values averaged over a pedal stroke when riding at 200 W. Shades of gray are scaled to maximum pressure in trial, with the maximum pressure shown in black. The pressure distributions highlight the concentrated anterior pressure that was commonly observed among the females when riding in the drops hand position.

and cadence, force that was lifted off the saddle was probably redistributed to the handlebars. It was found that females (but not males) increase normalized vertical force in the anterior region when going from the tops to the drops hand position. This effect is similar to the gender difference in anterior maximum pressure and may also be related to the pelvic geometry differences already discussed.

The relatively high sample rate used to collect the pressure data (100 Hz) provided insights into the variations in magnitude and location of saddle loading that occur throughout a pedal stroke. Minimum saddle loading coincided with the downstroke when vertical forces on the pedals were large (1). Peak saddle loading occurred slightly before bottom dead center which is consistent when pedal forces are smaller (9). Between crank angles of 100° and 160°, load on the saddle tended to shift from the posterior to the anterior region and from the driving-leg side to the recovery-leg side (Fig. 4). The forward motion of the posterior center of pressure on the driving limb side during the downstroke likely occurs as a result of soft tissue in the upper medial thigh contacting the transition region and anterior of the saddle as the limb is extended. Correspondingly, the posterior loading on the recovery-leg side of the saddle coincides with hip flexion such that the pelvis is interfacing with the saddle more distinctly with the bony pelvic structures and less with soft tissue.

Normal force vectors to the saddle surface geometry were used to resolve the vertical and ML components of the measured sensor forces (Fig. 3). AP force components were also resolved, but were relatively small. We found that isolating the vertical force component reduced the magnitude and inter-subject variability in the ensemble force curves (Fig. 4), when compared to simply summing the measured normal forces (3). The reduced variability may result from not including the ML force components which may be more dependent on the interplay between an individual's pelvic geometry and the saddle curvature. However, there were limitations with our approach to resolving the force components: normal vectors were computed for an unloaded saddle, so small deformations of the shell caused by loading the saddle would affect the surface normal directions in a way that was not taken into account. Also, the pressure sensors did not measure shear force, which would contribute to both the net vertical and ML forces acting on the rider.

Recent studies have shown that saddle design can affect blood flow in the perineal region (7,17), which is another measure to consider in assessing comfort and the cause of saddle-related pathologies such as numbness (5,18) and erectile dysfunction (6,7,16,17,19). Future studies which can couple pressure distribution and blood flow measurements seem important to better understand potential links between these factors.

Bicycle fit is clearly an important factor when measuring saddle pressure distributions. We chose to have all subjects ride on a horizontally level saddle and a standardized bicycle geometry, so as to offset potential influences of individual variations in bicycle setup and saddle inclination. However, this did require subjects to ride on a bike setup that could differ from what they are normally used to.

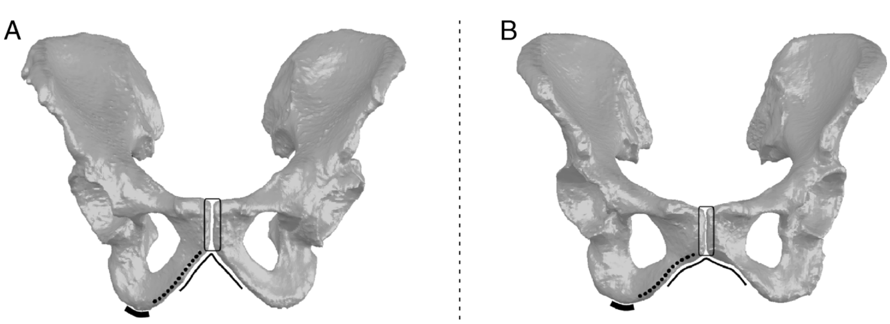

FIGURE 9—Front view of typical male (a) and female (b) pelvises with the following structures indicated: IT (superior to thick solid line), ischiopubic ramus (dotted line), pubic arch (thin line), and pubic symphysis (cartilaginous connection at location of rounded rectangle).

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It has previously been shown that saddle variations such as cutouts (12) and noseless (8) designs can alter the spatial distribution of pressure on the saddle. The results of our study demonstrate that factors other than cutouts can also influence saddle loading in the anterior region. All subjects rode *saddle A* (Fig. 1), a gender-neutral saddle, which has a standard geometry and structural stiffness, relatively thin cushioning, and no relief features designed into the perineal region. Nine of the 11 females also were tested on *saddle B* (Fig. 1) which, compared to *saddle A*, is somewhat wider in the rear and transition region and has increased compliance in the perineal region. Our results show that females experienced significantly lower normalized anterior maximum pressure when riding *saddle B* compared to *saddle A*. Although further study is needed to ascertain how such changes in pressure affect perceived comfort and injury risk, our results support the idea that females would probably achieve better bony support from a saddle which is slightly wider in the posterior region to accommodate the greater IT widths. In addition, relief features in the transition region and nose, such as increased cushion compliance or an indentation in the shell, may be especially beneficial for females to reduce pressure on anterior pelvic structures.

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