Bicycle Seat Designs and Their Effect on Pelvic Angle, Trunk Angle, and Comfort

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ABSTRACT

BRESSEL, E., and B. J. LARSON. Bicycle Seat Designs and Their Effect on Pelvic Angle, Trunk Angle, and Comfort. *Med. Sci. Sports Exerc.*, Vol. 35, No. 2, pp. 327–332, 2003. **Purpose:** To examine whether bicycle seats with anterior-medial cutouts influence pelvic angle, trunk angle, and comfort in female subjects during cycling. **Methods:** Twenty female cyclists pedaled a stationary bicycle with their hands on the tops and drops of the handlebars under three different saddle conditions (standard, partial, and complete cutout designs). Pelvic angle was measured using an inclinometer attached to a caliper whereas trunk angle was quantified from digitization of video images. Comfort level was assessed subjectively by having participants rank the saddles from most to least comfortable. **Results:** Anterior pelvic tilt angles for the partial and complete cutout saddles were 8% and 16% greater, respectively, than values for the standard saddle condition ($P < 0.05$). Trunk flexion angles were greater for the complete versus standard and partial cutout designs ($P < 0.05$). Participants displayed a 77% greater anterior pelvic tilt angle and an 11% greater trunk flexion angle in the drop versus top handlebar positions ($P < 0.05$). A total of 55% of the subjects ranked the partial cutout saddle as the most comfortable, and 30% ranked the standard saddle as the most comfortable. **Conclusions:** These data indicate that partial and complete cutout saddle designs may increase anterior pelvic tilt, and saddles with a complete cutout design may increase trunk flexion angles under select cycling conditions. A saddle with a partial cutout design may be more comfortable than a standard or complete cutout saddle design. **Key Words:** BIOMECHANICS, ERGONOMICS, SPINE, BACK PAIN, POSTURE

Over the years, manufacturers of bicycle seats have frequently altered the construction of the seat to improve its comfort and function. Recently, several manufacturers (e.g., Serfas, Lake Forest, CA) have redesigned the bicycle seat (or saddle) to better accommodate female anatomy and to avoid possible impotence in males. These newly designed bicycle seats are constructed with either no or minimal filling at the anterior-medial region, resulting in a partial or complete cutout configuration (e.g., Fig. 1). The primary purpose of the cutout is to decrease pressure to the anterior perineum, an area of pain and trauma often suffered by men and women during bicycling (2,17).

Perineal pain during bicycling is often related to the cyclist's position on the bicycle (5,8,11). For example, research has indicated that classic road and time trial positions increase the likelihood of pressure placed on the anterior perineum in experienced cyclists (15) and has been reported to cause bladder infections and painful skin breakdown in women (5,17,18). In general, perineal pain is a more frequent complaint among women as opposed to men cyclists (5) and is thought to be the most common nontraumatic pain syndrome experienced by women cyclists (17). Epidemiological studies, although not all specific to women, support this contention and have indicated that 35–81% of cyclists complain of pain in the perineum and buttock region after long-distance rides (1,2,5,18).

Researchers have reported that low back pain among men and women cyclists occurs at rates of up to 50% (14) and may also be related to the cyclist's position on the bicycle (8,14). To help reduce the incidence of low back pain, researchers have suggested a forward pelvic tilt is favorable as it decreases lumbar flexion and tensile stress to the longitudinal ligaments of the lumbar spine (8,14). Additionally, a forward or anterior tilt of the pelvis and trunk may help distribute a greater percentage of body weight over the handlebars, thereby reducing the load placed on the seat and lumbar vertebrae of the spine (8). Although there is evidence to suggest that the anterior pelvic and trunk tilt may reduce the incidence of low back pain (14), it would be expected that this forward tilt would also increase the pressure placed on the anterior perineum.

The newly designed cutout seats may relieve perineal pain and allow the pelvis and trunk to move into a greater anterior tilt position. If female cyclists are able to achieve a forward pelvic and trunk tilt without perineal pain, their comfort level during bicycling may increase and their incidence of low-pack pain may decrease. It was, therefore, the purpose of this study to determine whether a woman's pelvic angle and trunk angle are changed when using a standard bicycle saddle versus a saddle with either a partial or complete cutout. A secondary purpose was to assess the

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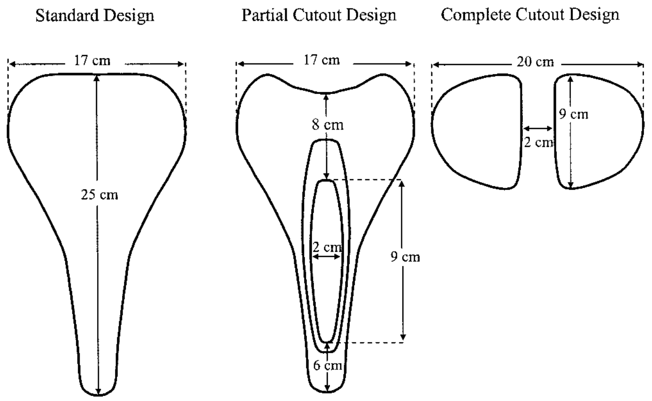

FIGURE 1—A top view of the three saddle designs and their physical dimensions.

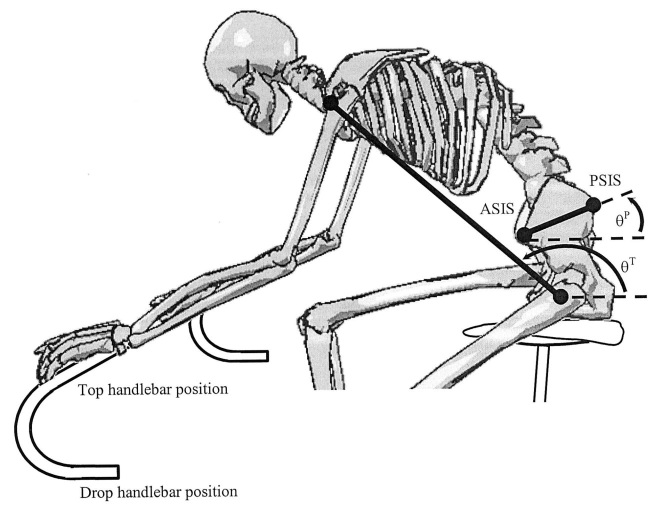

FIGURE 2—Schematic diagram of the conventions used to specify angular displacements (*θ*) about the pelvis (P) and trunk (T). Subjects exercised in the top then drop handlebar positions while testing; ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine.

level of comfort each seat provided based on subjective ranking.

We hypothesized that pelvic angle, trunk angle, and comfort would be different between a standard saddle and a saddle with an anterior-medial cutout. Because experienced cyclists are accustomed to placing pressure on the anterior perineum (15), we suspected the findings may be different between novice and experienced cyclists. If pelvic or trunk positions change in response to saddles with anterior-medial cutouts, the proportion of body weight distributed over the handlebars may change as suggested by de Vey Mestdagh (8) and thus influence spinal loads (8). Accordingly, we felt it was important to appreciate how each saddle design may influence weight distribution by examining EMG activity of the triceps brachii muscle. We hypothesized the activity of this muscle would change in response to different saddle designs.

METHODS

Participants. Ten novice and 10 experienced female cyclists were asked to volunteer for this study. The number of subjects chosen was calculated using SamplePower software (SPSS Inc. Chicago IL) and was based on an effect size of 0.25 SD (6) with an alpha level of 0.05 and power at 0.80. Participants were recruited from a local community and university population through posted advertisements. Cycling experience level was determined based upon miles biked per week. The experienced cyclists rode greater than 50 miles·wk^{-1}. Participants were included in the study if they were free of leg pain, back pain, perineal pain, and impairments to the active limbs. The participants displayed the following physical characteristics (mean $\pm$ SD): experienced = age 27.14 $\pm$ 5.15 yr, mass 63.57 $\pm$ 9.38 kg, and height 1.65 $\pm$ 0.07 m; and novice = age 21.00 $\pm$ 1.41 yr, mass 66.01 $\pm$ 8.85 kg, and height 1.67 $\pm$ 0.08 m. Before taking part in the study, participants read and signed an informed consent form approved by the institution's ethics committee.

Procedures and instrumentation. The experimental design of this study required each participant to pedal a stationary bicycle ergometer under three different saddle conditions while pelvic angle, trunk angle, and EMG signals were recorded. The three saddle conditions were: a) standard sport saddle with no cutout (Velo DDL-200, Serfas); b) sport saddle with a partial anterior-medial cutout (CRZ+, Trek Bicycle Corp., Waterloo, WI); and c) sport saddle with a complete anterior cutout (Spongy Wonder Inc., New Brunswick, Canada). The physical dimensions of each saddle are shown in Figure 1.

Participants rode on each saddle for 8 min: the first half of the exercise bout was performed with their hands on the tops of the handlebars and in the drops for the second half (see Fig. 2). Hand positions were changed to better reflect real cycling conditions and to influence pressure placed on the anterior perineum. The order of hand positions was not randomized to correspond with real cycling conditions where cyclists initially ride (or warm-up) in the top then move to the drop handlebar position. For each saddle condition, participants pedaled at an external work rate of 140 W (80 rpm) using a metronome to maintain the target pedaling rate. The three exercise bouts were separated by a 5-min rest period and were randomized to prevent an order effect. Before cycling, participants warmed-up for 5 min while exercising on an elliptical trainer (ProForm 695E, ICON Health & Fitness, Logan, UT) at a self-selected intensity.

Participants performed the three exercise bouts on a modified Monark ergometer (Monark-Crescent AB 824E, Varberg, Sweden). Modifications were made to the stem, bars, and seat post, which enabled for the installation of drop bars and precise adjustments in height and fore and aft positions to the seat and handlebar. The seats were set level and at a height of 98% of inseam length. The fore and aft position of each seat was set so a plumb bob positioned below the left tibial tuberosity fell within 2 cm of the pedal axis when the cranks were positioned parallel with the floor with the left leg forward. The first metatarsal head of the foot was positioned over the pedal axis by using cleated shoes or toe straps to maintain position. The handlebar height was set approximately 6 cm below the seat, and handlebar reach was set according to averages described by de Vey Mestdagh (8). Once the ergometer was properly set-up, it did not change for each condition except for the saddle itself.

Pelvic angle, defined according to Figure 2, was measured during each exercise bout at min 0:00, 1:00, 02:30, 04:00, 05:00, 06:30, and 08:00 using an inclinometer (Uni-Level, ISOMED, Inc., Portland, OR) attached to a custom deep caliper that provided the following features: extended asymmetric arms, resistance clamp to pressurize bony landmarks, and a bubble level to ensure the inclinometer was in the sagittal plane at the time of measurement. The assessment of pelvic angle required the participant to stop pedaling and to hold her body completely still with the cranks positioned parallel to the floor. Then, one researcher positioned and firmly pressurized the caliper arms over the participant's left anterior and posterior superior iliac spines while a second researcher, blinded to the purpose of the study, recorded the angle directly from the inclinometer. Before exercising, participants were provided visual and tactile feedback regarding the location of their bony landmarks and were asked to give feedback during assessments if they felt the caliper arms were improperly positioned. No subjects reported a misalignment of caliper arms during assessments.

Studies examining intratester reliability of the pelvic angle assessment employed in this study reported intraclass correlation coefficients (ICC) of 0.83–0.96 (9,10,16). Although these ICC values were convincing, we felt it was important to examine intratester reliability and criterion-related validity by using our equipment and procedures. Standard radiographic images of the pelvis from a lateral view were made on 10 healthy volunteers positioned on the modified Monark ergometer with the standard saddle. Pelvic angle was measured immediately before the radiographic assessment by using the aforementioned procedures. The procedures were then repeated immediately after the radiographic image was captured. An ICC value for the test-retest assessment of pelvic angle was 0.98 ($F_{1,9} = 126$), and the relationship (i.e., Pearson product-moment correlation coefficient, *r*) between radiographic assessment of pelvic angle and the assessment used in this study was 0.90 ($P = 0.01$). Researchers often consider correlation coefficients greater than 0.90 as indications of excellent reliability and validity (3,9).

Trunk angle, defined according to Figure 2, was continuously monitored throughout the exercise bouts with a video camcorder (Panasonic AG-188U; 60 Hz with a shutter speed of 0.002 s) placed in the sagittal plane at a distance of 5.8 m from the object points at a height of 0.8 m from the floor. Standard videography procedures were implemented (12). Reflective markers (1 cm $\times$ 1 cm) were applied to the skin over the following bony landmarks of the left side to aid in subsequent digitizing: lateral aspect of acromion process and greater trochanter of femur.

Comfort level of each saddle was assessed by having participants subjectively rank the saddles from most to least comfortable. Participants were asked to rank the saddles after testing was completed.

EMG activity of the left triceps brachii muscle (long head) was recorded for 3 s before each pelvic angle assessment with bipolar surface electrodes (DelSys 2.01, Boston, MA) placed over the muscle belly according to Cram and Kasman (7). EMG signals were sampled at 1000 Hz between a bandwidth of 20–450 Hz and amplified using a DelSys Bagnoli 4 amplifier (DelSys Inc.). The root mean square of the raw EMG data was calculated and normalized to a maximum voluntary isometric contraction recorded at the completion of testing. For this latter assessment, subjects exerted a maximal 5-s shoulder and elbow extension action in the drop handlebar position. The EMG activity could then be expressed as a percentage of the activity recorded during their maximum isometric voluntary contraction.

Data analysis. Pelvic angle data were averaged over the final 3 min for each hand position of each saddle condition. This analysis provided a mean pelvic angle measure for each saddle condition with hands in either the tops or drops of the handlebars. A greater mean pelvic angle indicated an anterior pelvic tilt (Fig. 2).

Angular displacement of the trunk was calculated from coordinate data taken from the digitization of reflective markers by using a motion analysis system (Peak Performance Technologies, Inc., Englewood, CO). The digitization process included one cycle of pedaling (0–360°) that coincided with each EMG data collection period. Coordinate data were smoothed using a fourth-order, zero-lag Butterworth low-pass filter. Kinematic data were based on a two-dimensional, one-segment model of the trunk. A greater mean trunk angle indicated trunk flexion (Fig. 2).

Statistical analysis. The independent variables in this study were saddle design (standard, partial cutout, and complete cutout), hand position (tops and drops), and cycling experience level (novice and experienced). The dependent variables were pelvic angle, trunk angle, and EMG activity. Dependent measures were examined for main effects and interactions with a three-factor ANOVA ($3 \times 2 \times 2$) with repeated measures on the saddle design and hand position factors. Follow-up multiple comparisons were conducted on the saddle design factor. The probability associated with a Type I error was set at 0.05 for all observations. Saddle comfort data were analyzed descriptively.

RESULTS

Pelvic angle responses. The three-factor ANOVA revealed a significant main effect for saddle design ($F_{2,17} = 8.34$, $P = 0.001$) and hand position ($F_{1,18} = 242.03$, $P = 0.001$) factors. The results showed no significant main effect for cycling experience level ($F_{1,18} = 1.97$, $P = 0.18$) and no significant interactions ($P > 0.05$). Follow-up multiple comparisons conducted on the saddle design factor indicated that mean pelvic angle values for the partial and complete cutout saddle were 8% and 16% greater, respectively, than values for the standard saddle condition (Table 1). No differences were found between the partial and com-

TABLE 1. Pelvic and trunk angle values (mean ± SEM) for novice ($N = 10$) and experienced ($N = 10$) participants riding on the standard, partial cutout, and complete cutout saddles.

Measure and Variable	Standard	Partial Cutout	Complete Cutout
Pelvic angle (°)			
Novice	18.69 (2.11)	19.97 (1.98)	22.36 (2.28)
Experienced	22.70 (2.11)	24.74 (1.98)	25.63 (2.29)
All participants	20.70 (1.49)	22.36 (1.40)[a]	24.00 (1.62)[b]
Trunk angle (°)			
Novice	146.95 (1.31)	146.53 (1.05)	148.53 (1.07)
Experienced	149.11 (1.31)	148.40 (3.11)	149.57 (1.07)
All participants	148.03 (0.93)	147.47 (0.74)	149.05 (0.76)[b]

[a] $P < 0.05$, significantly greater than standard saddle condition.
[b] $P < 0.05$, significantly greater than standard and partial cutout saddle conditions.

plete cutout saddle conditions. Participants displayed a 77% greater pelvic angle in the drop versus top handlebar position (Table 2).

Trunk angle responses. Similar to the pelvic angle results, a significant main effect for saddle design ($F_{2,17} = 7.94$, $P = 0.001$) and hand position ($F_{1,18} = 1555.94$, $P = 0.001$) were found for the trunk angle variable. The ANOVA showed no significant main effect for cycling experience level ($F_{1,18} = 1.18$, $P = 0.29$) and no significant interactions ($P > 0.05$). Follow-up multiple comparisons indicated that trunk angles for the complete cutout saddle were 1% greater than the standard and partial cutout saddles (Table 1). Multiple comparisons revealed no other differences in which this variable was included. Participants displayed an 11% greater trunk angle in the drop versus top handlebar position (Table 2).

Seat comfort responses. Overall, 11 subjects (55%) ranked the partial cutout saddle as the most comfortable, and 6 (30%) ranked the standard saddle as the most comfortable. A similar trend was observed for each group. That is, six (60%) experienced subjects ranked the partial cutout saddle as the most comfortable, and three (30%) ranked the standard saddle as the most comfortable. Fifty percent of the novice group reported greater comfort with the partial cutout saddle, and 30% indicated greater comfort with the standard saddle design.

EMG responses. The ANOVA revealed a significant main effect for the saddle design factor ($F_{2,17} = 3.88$, $P = 0.03$) and a significant saddle design by hand position interaction ($F_{2,17} = 8.49$, $P = 0.001$). No other effects or interactions were observed. Follow-up comparisons indicated that normalized EMG values of the triceps brachii muscle were 16% and 10% greater for the complete cutout saddle versus the standard and partial cutout saddle conditions, respectively (Table 3). The results of the interaction are illustrated in Figure 3 and demonstrate that the complete cutout saddle influences EMG activity of the triceps brachii muscle to a greater extent when participants pedaled in the top versus the drop handlebar position.

TABLE 2. Pelvic and trunk angle values (mean ± SEM) for novice ($N = 10$) and experienced ($N = 10$) participants riding with their hands on the tops and drops of the handlebars.

Measure and Variable	Tops	Drops
Pelvic angle (°)		
Novice	14.02 (1.95)	26.66 (2.24)
Experienced	18.21 (1.95)	30.51 (2.24)
All participants	16.11 (1.38)	28.59 (1.59)[a]
Trunk angle (°)		
Novice	139.20 (1.23)	155.48 (1.04)
Experienced	141.88 (1.23)	156.18 (1.04)
All participants	140.54 (0.87)	155.83 (0.73)[a]

[a] $P < 0.05$, significantly greater than top handlebar position.

TABLE 3. Normalized EMG values (mean percentage, ± SEM) for novice ($N = 10$) and experienced ($N = 10$) participants riding on the standard, partial cutout, and complete cutout saddles.

Muscle and Variable	Standard	Partial Cutout	Complete Cutout
Triceps brachii			
Novice	23.88 (4.43)	25.28 (4.05)	29.12 (4.67)
Experienced	20.95 (4.43)	21.91 (4.05)	22.90 (4.67)
All participants	22.41 (3.14)	23.59 (2.86)	26.01 (3.30)[a]

[a] $P < 0.05$, significantly greater than standard and partial cutout saddle conditions.

DISCUSSION

As a cyclist leans forward onto the handlebars of a bicycle, undesirable pressure is often applied to the anterior perineum. Recent bicycle seat designs may decrease this pressure by eliminating portions of the saddle that make contact with the perineum. These newly designed saddles may improve comfort but also may encourage a forward pelvic and trunk tilt. The present study examined these latter ideas and found that bicycle saddles with an anterior-medial cutout design, either partial or complete, increased anterior pelvic tilt angles and saddles with a complete cutout design increased trunk flexion angles. The majority of subjects reported greater comfort when riding a partial cutout saddle design.

Direct comparisons of mean pelvic angle data across studies were difficult due to the different manner in which pelvic position was measured. Salai et al. (14) used a radiographic technique to measure the influence of saddle angle on pelvic angle in 10 healthy male subjects. They reported a greater forward pelvic tilt and a decreased tensile

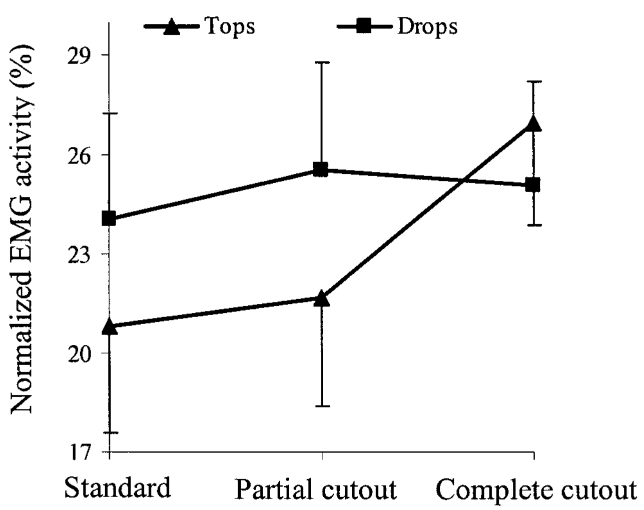

FIGURE 3—Normalized EMG activity values (mean, SEM, $N = 20$) for the standard, partial cutout, and complete cutout saddle conditions while participants rode with their hands on the tops and drops of the handlebars. A significant saddle design by hand position interaction was found.

stress to the longitudinal ligaments of the lumbar spine with a downward tilting saddle. Salai and coworkers then applied their findings to a group of subjects exhibiting low back pain. Saddle tips were angled downward 10–15°, and after 6 months of bicycling activity, 70% of the subjects reported decreased low back pain. The results of the present study indicated that horizontally level saddles with anterior-medial cutouts may also increase a forward pelvic tilt during bicycling. Whether these newly designed saddles decrease low back pain is yet to be determined.

Neptune and Hull (13) examined pelvic motion during cycling by using video analysis of reflective markers attached to the anterior superior iliac spine and a triad of markers attached to an intracortical pin inserted into the lateral iliac crest. One of their objectives was to assess accuracy of kinetic data derived from video analysis of reflective skin markers placed over the hip joint center. Although they did not report pelvic inclination angles for comparison, they did suggest that soft tissue movement and marker misalignment may introduce errors in subsequent kinematic and kinetic calculations. Pilot testing for the present study revealed that some female participants exhibit a thick soft-tissue layer over their anterior and posterior superior iliac spines that may accentuate soft tissue movement and misalignment of markers (4). These limitations and the minimal dynamic movement expected at the pelvis during cycling (i.e., $< 3°$) (13) led to use of the inclinometer technique in this study. Although pelvic angle values in this study appear to be reliable and valid, the technique is limited because it requires a static posture that prevents an appreciation of dynamic motion of the pelvis and spine.

The results of the present study indicated that saddle designs with anterior-medial cutouts may enhance an anterior pelvic tilt regardless of hand position (tops or drops of handlebars) and experience level of the participant (novice or experienced). Although these findings are original and may be appealing because of the potential for reduced stress on the lumbar spine during cycling (14), a complete anterior cutout design may not be practical during real cycling conditions that rely on the anterior region of the saddle for stability and steering (8). Additionally, the complete cutout saddle may be the least comfortable design as reported by the subjects in this study. The partial cutout design may be a good compromise as it maintains stabilizing features of the standard saddle, increases anterior pelvic tilt, and may improve comfort. Subjective comfort data and pelvic angle data of this study support this latter contention, yet future work is needed to assess whether minor changes in pelvic tilt are sufficient to decrease low back pain in female cyclists.

We suspected that experienced cyclists would be less sensitive to perineal pain and more accustomed to an aerodynamic position, which may favor an anterior pelvic tilt or trunk flexion posture on the bicycle. Results indicated that pelvic angle and trunk angle were nonsignificantly greater for the experienced group by 20% ($P = 0.18$) and 6% ($P = 0.29$), respectively. A *post hoc* power analysis using data reported in Table 1 indicated the differences between groups may have been significant with a larger group sample size or with reduced variability in the measurements. One possible reason that statistical differences were not observed between groups was that statistical power was overestimated in the preliminary analysis.

Similar to pelvic angle data, greater trunk flexion values were observed with the complete cutout saddle design. Although the percent difference between saddles was not impressive (i.e., 1%), a greater trunk flexion angle or anterior pelvic tilt may influence weight distribution over the handlebars and therefore the load placed on the seat and lumbar vertebrae of the spine (8). EMG data of this study showed the triceps brachii muscle was more active when riding with a complete cutout saddle design (Table 3), indicating that greater weight may have been distributed to the handlebars. The effect of the complete cutout saddle design on EMG activity of the triceps brachii muscle may be more pronounced when riding in the top versus the drop handlebar position (Fig. 3).

In summary, this study gives evidence to the idea that bicycle seats designed to decrease anterior perineal pressure influence a cyclist's position on the bicycle. Specifically, the complete and partial cutout seats in this study increased anterior pelvic tilt angles and the saddle with a complete cutout increased trunk flexion angles regardless of hand position and experience level of the participant. The partial cutout design may be more comfortable than standard or complete cutout seats. Current work in this area is examining seat pressure and comfort during prolonged cycling conditions.

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