Sports Technology

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Design and Test of Cycling Shorts Padding on Pressure Distribution and Perceived Discomfort in Female Cyclists during Ergometer Cycling

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Abstract

Increasing evidence back up the prevalence of genital discomfort and non-traumatic injuries in female cyclists. However, to my knowledge no study has so far been performed to design and investigate the effect of cycling shorts pads in female cyclists. The objective of the present study was to assess the differences in discomfort and saddle pressure distribution as a function of cycling shorts pad design. Two pad designs were designed and produced; a traditional pad with padding at the ischial tuberosities and crotch area (full-pad) and a novel pad with padding exclusively at the ischial tuberosities (half-pad). Fourteen female club cyclists pedaled a on a cycle ergometer for one hour at a constant power output (130 W) and a target cadence of 80 (80±3 rpm) with two pad designs in blinded counterbalanced order over two separate sessions. Pressure measurements by means of a pressure mat were made and the rate of perceived discomfort for the ischial tuberosity and crotch area was measured by means of a visual analogue scale. Further rate of perceived discomfort was conducted for subdivision of the crotch area. Pad design elicited no effect on the variability of center of pressure in anterior-posterior and medial-lateral direction nor rate of perceived discomfort in the ischial tuberosity- or crotch area, suggesting a low effect padding in the crotch area. Session order effect may however suggest an adaption to discomfort at the ischial tuberosities, while adaptation to crotch discomfort was less marked.

Keywords: Female, cycling, COP variability, sample entropy, perceived discomfort.

1. Introduction

Physical activity by cycling can reduce all-cause mortality (Andersen et al., 2017; Matthews et al., 2018) and cycling has, as a recreational activity for women in Denmark, been increasing since 1999 to 2017 by 105%[1]. However, recent literature on non-traumatic injuries in female cyclists (Hermans et al., 2016; Trofaier et al., 2016) and case studies reveal a relatively high occurrence of non-traumatic injuries at the genitalia. Meanwhile women have also been found to suffer the most of discomfort during cycling, as compared to men (74% vs. 55%) (Christiaans and Bremner, 1998). In spite of a relatively high occurrence of

[1] https://www.dif.dk/da/forbund/forbund/danmarks-cykle-union

non-traumatic injuries in the genital area (Fig. 1.1) in female cyclists, sparse literature has been focused on females, ergonomics and sitting comfort during cycling (Keytel and Noakes, 2003; Larsen et al., 2018). The primary focus of the present literature on saddle design have focused on the impingement of pudendal

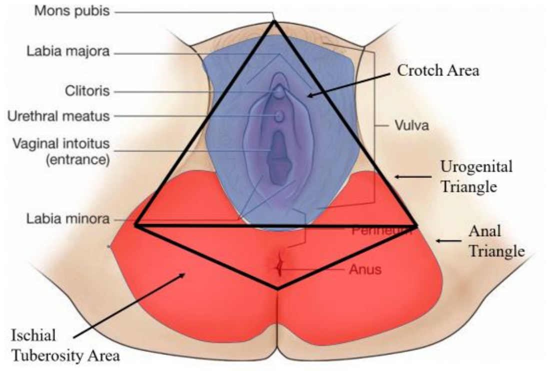

Figure 1.1: Female perineum, as defined by the two triangles; the urogenital triangle and the anal triangle, with subdivisions of ischial tuberosity area and crotch area used for the assessment of the rate of perceived discomfort. The illustration is adapted from[2].

nerve and arteries during cycling, primarily in men (Lowe et al., 2004; Nayal et al., 1999; Schrader et al., 2002; Schwarzer et al., 2002), but also in women (Guess et al., 2006). However, another matter of discomfort and injury prevalence seems to be of more urgent character for the female cyclist; discomfort and injuries at the external genitals.

Hermans et al. (2016) reported an occurrence of 34.9% and 40% genital numbness and vulvar discomfort (lasting for a maximum of 48 hours) in 114 female cyclists members of the largest cycling association in the Netherlands after at least two hours of cycling, while Guess et al. (2006) reported genital pain, tingling or numbness within in the last month of the study in 63% of 48 competitive female cyclists, who rode an average of at 45. km per day 3.8 times per week, while case studies of female cyclists have demonstrated severe cases of vulva hypertrophy and local scar tissue at the external genitals (Baeyens et al., 2002; Humphries, 2002). Buller (2001), questioning 52 symptomatic female cyclists, reported the discomfort sensation, with 81% describing their symptoms as “burning” or “pain”, while 70% described their symptoms as numbness and 14% described their symptoms as “pins and needles”.

Previous literature (Bressel and Cronin, 2005; De Vey Mestdagh, 1998) suggest female cyclist to increase handlebar height to relieve anterior pressure. However, this solution is not desirable for the competitive athlete, as the sportive position with a greater trunk flexion is adopted to improve aerodynamics (Fintelman et al., 2014). The effect of discomfort caused by the saddle on cycling performance in still unclear, however previous studies have established a strong effect of comfort on injury prevention and

[2] https://bit.ly/2szwnLd

enhancement of performance in e.g. running, soccer, and basketball (Priego Quesada et al., 2016). Regardless, it is desirable to optimize the sitting conditions of the female cyclists, independent of the objective of cycling; competition or commute.

Padding in cycle shorts are designed to provide comfort and aid against overuse injuries in the perineal area, as claimed by manufacturers, and is considered an fundamental piece of accessory for the cyclist (Marcolin et al., 2017), suggested to prevent skin chafing (Thompson and Rivara, 2001). However, sparse literature addresses this subject (Marcolin et al., 2017, 2015, 2010) and very little is known about the workings of these pads. Looking into the literature of saddles, saddle evolution has aimed to reduce pressure on the perineal area by combining ergonomic geometry and padding (Breda et al., 2005). Meanwhile, it have been established that apparent differences in pressure distribution on bicycle saddles are present between the sexes (Potter et al., 2008; Sauer et al., 2007). However, considering the current female´s pads on the market, a wide variety is available. Despite a wide range of female's cycling shorts pads it does not seem as if any consistency is present in the design of female specific pads for cycling shorts.

It is agreed that pressure relief by pressure-reducing cushioning have been found useful in prevention of pressure ulcers in sitting individuals primarily over bony prominences (Defloor and Grypdonck, 2000; Mohanty and Mahapatra, 2014),with different interface pressure reduction depending on cushioning material and density (Defloor and Grypdonck, 2000; Marcolin et al., 2015). Meanwhile, glancing to the saddle literature, heavy padded saddles have been suspected to cause compression of the perineal area (Gemery et al., 2007), while saddle geometry has also been suspected to be of greater importance than saddle padding (Sequenzia et al., 2016), implying that padding at the bony prominences of the ischial tuberosity may play a greater role in the aim to prevent skin degeneration and thereby discomfort, while padding in the crotch area may play a less important role, as the excessive padding may cause greater harm than good.

Postural control variability as assessed by center of pressure (COP) trajectory has become a more recognized tool for assessment of movement parameters, instead of an expression of measurement noise (van Emmerik and van Wegen, 2002). In the present study, the rate of perceived discomfort (RPD) by a visual analogue scale (VAS) in the perineal interface was sought associated with COP variability measures. Previous studies (Fenety and Walker, 2002; Søndergaard et al., 2010; Vergara and Page, 2002) have associated variability measures with changes in seated posture related to discomfort. Fenety and Walker (2002) found temporal growth of discomfort to be related to COP changes, while Vergara and Page (2002) found micro movements to be the preliminary cause of discomfort. Søndergaard et al. (2010) demonstrated an association by correlation between seated discomfort during static seating without support and variability (standard deviation (SD) of COP) and regularity (sample entropy) measures. Søndergaard et al. (2010) found the increase of SD of COP to be interrelated to increasing discomfort, while increased regularity by sample entropy interrelated with increasing discomfort.

The purpose of the present study was to design, produce and assess the differences in discomfort and biomechanics as a function of cycling shorts pad design. Two cycling shorts pads with similar posterior layout but different anterior layout were designed and produced. Effects of pad design were evaluated by COP variability and regularity and RPD were obtained and evaluated. It was hypothesized that the differences in cycling shorts pad design would elicit differences in COP variability and regularity, and RPD. Meanwhile, it was further hypothesized that an association between RPD and COP variability would show, with increasing COP variability and increasing regularity interrelating with increasing discomfort, in agreement with the findings of Søndergaard et al. (2010).

2. Method

2.1 Participants

Fourteen female club cyclists (age 35.2±11.8 yr, body mass of 61.5±5.7 kg, height 1.662±0.062 m, BMI 22.3±1.5 kg/m^2, skeletal muscle 26.3±2.9 kg, body fat 22.5±4 %, road cycling experience 3.6±2.4 yr, average training amount per week 5.5±2.2 h, average distance per week 147.1±58.7 km) volunteered to participate in the study. Participants were included if they cycled an average minimum of 3 h per week in the summer period (Marts-October), were asymptomatic, had no injuries to the lower extremities or back, and was accustomed to use a stationary bicycle. The minimal training hours per week for inclusion criteria were arbitrary chosen but were chosen to ensure that the participants reflected avid club cyclists. Participants were excluded if they were pregnant or had had a vaginal delivery within the last 12 months. Prior to participation, participants were informed about the procedure and signed an informed consent. Lastly, participants completed a bicycle and genital injury history questionnaire, inquiring about bicycling practices and non-traumatic bicycling injuries.

2.2 Cycling Pad Design

To test the effect of padding in the crotch area, two different pads with similar posterior layout, but different anterior layout were designed and produced (Fig. 2.1). The posterior design refers to the accommodation of the ischial tuberosities, while the anterior design refers to the accommodation of the crotch area. The full-pad was designed with padding both posteriorly and anteriorly, while the half pad was designed without padding anteriorly, exclusively providing padding at the posterior part. The posterior part of the saddle was designed as two separate oval-shaped padding geometries with an inner semi-minor axis diameter of 65 mm and an inner semi-major axis diameter of 80 mm (Fig. 2.1), with 130 mm between the center

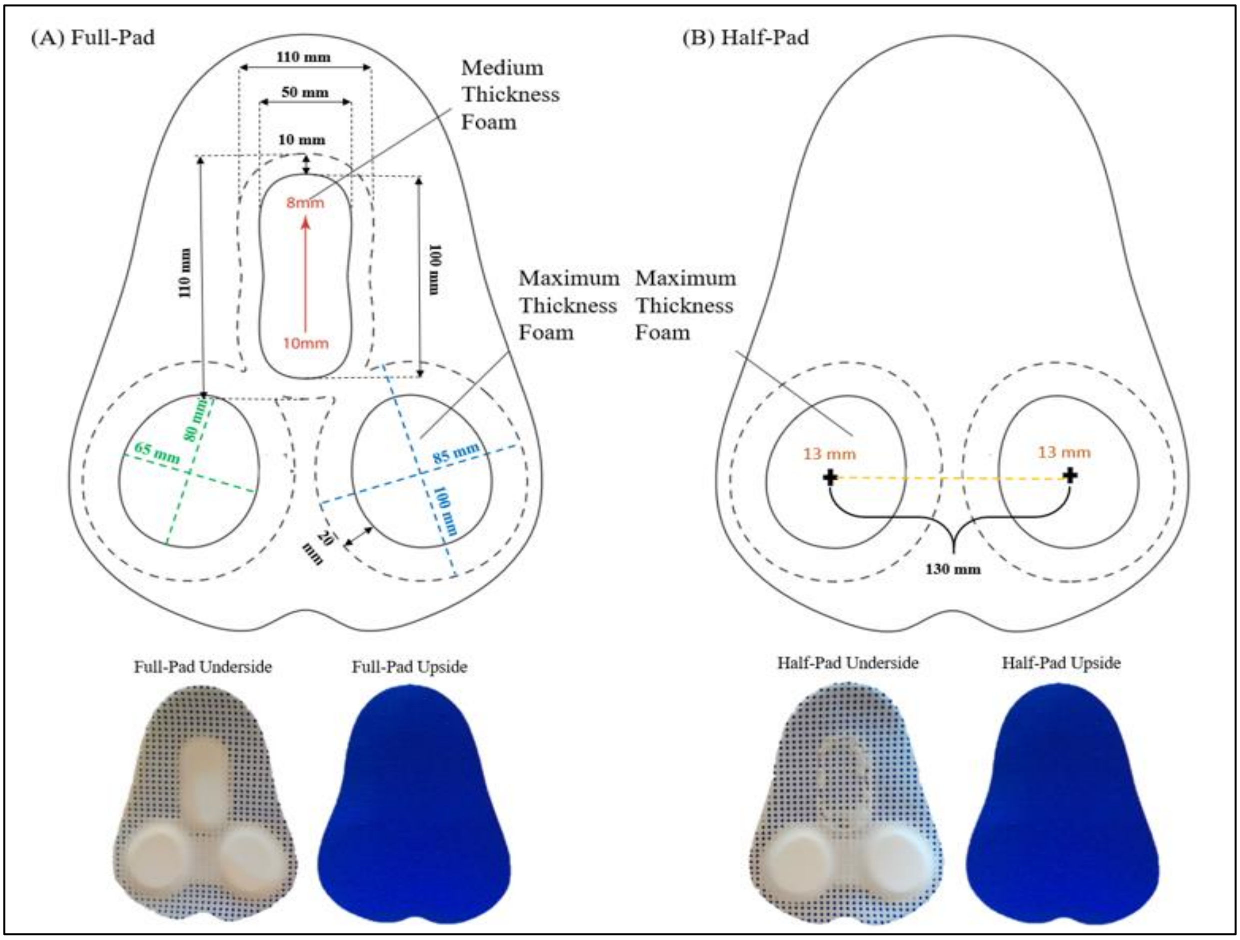

Figure 2.1: Geometry and dimensions of full-pad design (A) and half-pad design (B). Dotted lines define the outer geometry of the foam padding, while full lines define the inner geometry. Transition from padding to no padding is conducted by phase out by milling by 20 mm in the posterior geometry and 10 mm in the anterior geometry.

of each oval-shaped padding. The anterior rectangular geometry was designed with an inner length of 100 mm and inner width 50 mm. Phase out of the foam padding by milling of 20 mm in the posterior padding and 10 mm in the ensured smooth transition from padding to no padding. The padding consists of a cross-linked polyolefin foam, with a density of 50-120 kg/m^3 depending on the thickness of the padded areas (Fig. 2.1, A). The thickness is 13 mm in the posterior region, and a varying milled thickness in the crotch area (10-8 mm) from posterior to anterior direction. The 13 mm oval posterior padding area was phased out with a 20 mm milling as to ensure a smooth transition from padding to no padding. The oval shape of the anterior padding area was phased out over 10 mm.

2.3 Study Design and Experimental Setup

A blinded counterbalanced cross-over study design with participants attending two laboratory sessions of respectively 105 and 90 min each day was constructed. Participants attended the sessions with a minimum of 48 h and maximum of 1 week between sessions (89±52 h) as to allow for residual effects to dissipate and strive for alike condition of the participant from session one to session two. The mean temperature of the laboratory for session one was 25±0.8°C and 25±1.2°C for session two.

A non-padded standard saddle, produced for a previous study (Larsen et al., 2018) was used in both sessions, as to eliminate effects of cushioning from the saddle (Hiemstra-van Mastrigt et al., 2017). Participants rode an SRM ergometer (Schoberer Rad Messtecknik, Jülich, Germany), with a flexible pressure mat (S2119, Novel, Munich, Germany) attached to the saddle to measure the interface pressure between the saddle and the buttock-crotch area. The pressure mat is arranged in 16 rows times 32 columns, each with a sensing area of 1 cm^2, counting a total of 512 censors. The S2119 was calibrated within the pressure range 0-350 kPa.

A digital visual analogue scale (VAS) (Aalborg University, Denmark) was attached to the handlebar of the SRM ergometer and was used to assess the rate of perceived discomfort (RPD) of respectively the ischial tuberosity area and crotch area, with zero representing no discomfort, and 10 representing maximum discomfort. A modified body part discomfort scale (Corlett and Bishop, 1976), restricted to the genitalia area only and scored by the VAS was used to determine the area and degree of discomfort in the crotch area. Pad rating was assessed by a numerical rating scale from 1 to 10, with 1 being the lowest liking and 10 the highest liking.

2.4 Procedure

Anthropometric measurements (Table 2.1) where conducted using a bio-impedance scale (InBody, Seoul, Korea) and a BIO SIZE anthropometric measurement tool (Bicisupport Srl, Casatenovo, Italy). Inside leg, arm, and torso length was used for bike fitting, to ensure standardized sitting conditions across subjects. Crotch height was measured bare food from level ground to pubis, arm length was measured from the superior part of the acromion to the first metacarpalia. Torso length was measured from the plane of stool, on which the participant was seated erect, to the incisura jungularis of the manubrium sterni.

Tabel 2.1: Anthropometric measures of participants (N = 14).

Variables	Mean±SD
Crotch height (m)	0.783±0.038
Torso length (m)	0.576±0.028
Arm length (m)	0.626±0.036
Hip width (m)	0.340±0.015
Thigh circumference (m)	0.583±0.030

Participants were randomly assigned a pair of cycling shorts, and while participants changed for cycling shorts, the SRM was adjusted as recommended by De Vey Mestdagh (De Vey Mestdagh, 1998) and Christiaans and Bremner (Christiaans and Bremner, 1998). Saddle height, the distance from the center of the pedal spindle in 180° position to mid top of the saddle was adjusted to 107% of crotch height; the preferred saddle height in terms of comfort in women (Christiaans and Bremner, 1998). Saddle set back was adjusted as such a straight vertical line can be drawn from the inferior pole of the patella to the 5th metatarsal, when the foot was placed in 90° position. Handlebar height was adjusted in relation to saddle height and was adjusted to 6 cm below saddle height for all participants (Larsen et al., 2018; Silberman et al., 2005). Reach, the distance from the rear of the saddle to the center of the handle bar, was determined from scale values based torso- and armlength (De Vey Mestdagh, 1998). Participants were instructed to remain seated throughout the whole hour, and thus were not allowed to relieve the discomfort by standing in the pedals. Likewise, participants were instructed to place hands at brake hoods and not to change between hand positions. Participants were allowed to consume water in between measurements.

Saddle pressure distribution was collected at a sample frequency of 35 Hz. Static measures of pressure distribution in right leg crank arm position 90° was collected for 10 s prior to the dynamic trials. Dynamic measures were conducted during 1 h of constant power output of 130 W, corresponding to 81% of the average elite female power output during a road race (Lim et al., 2011), while keeping a target cadence of 80±5 rpm. Monitored cadence turned out 80±3. Periods of pressure measurements were conducted for 55 s for every nine to 10th minute, generating 6 × 55 s periods. The RPD by the VAS at the ischial tuberosities and crotch area was assessed straight after pressure measurements for every bout. Participants were introduced to the area of discomfort prior to testing by illustration description clearly defining the of area ischial tuberosities and crotch. During periods, participants were shown the same illustration, and first asked for discomfort at the ischial tuberosities, followed by the crotch area. After assessment of the RPD at the ischial tuberosities and crotch area, participants were asked to define the area and degree of RPD by the VAS for subdivisions of the crotch (Fig. xx). Participants were shown an illustration with predefined areas in the crotch, of which they were instructed to say out-loud the area of discomfort and rate the degree of discomfort by VAS. When the 1 h cycling bout was over, participants were asked to rate their liking of the padding in the cycling shorts.

2.5 Data Analysis

Pressure data were processed in Matlab (MathWorks Inc., Natick, MA, USA). A 2nd order zero-lag Butterworth low pass filter with a cut-off frequency of 5 Hz was used for data filtering. A numerical template of the saddle top contour was defined in Matlab based on cells covering the saddle. Dubious force data prompted exclusion of pressure data, including only off-set corrected center of pressure (COP) measures, assessed by subtracting the first computed value in both anterior-posterior (AP) and medial-lateral (ML) direction. Center of pressure displacement was computed over an epoch of 1925 samples. Standard deviation (SD) of the absolute COP displacement in AP and ML direction were analyzed to determine the absolute size of variability. Coefficient of variation (CV) of COP displacement in AP and ML direction was computed to determine the relative size of variability. Sample entropy measures (SaEn) were used to determine the regularity of the variability of COP displacement, with an embedding dimension (*m)* of two and a tolerance distance (*r*) of 20% of SD (Verma et al., 2016). Sample entropy expresses the probability that two sequences of length *m* will remain similar for the next increment, *m+1*, within the tolerance distance *r*. The sample entropy value is a non-negative number that when great represents less similarity in the time series, and when small represents more similarity (Richman and Moorman, 2000), previously associated with greater seated discomfort (Søndergaard et al., 2010).

2.6 Statistical Analysis

Statistical analysis was conducted in SPSS 24.0 (IBM, Armok, NY, USA). Data is presented as mean ± standard deviation. Dependent variables were tested for normality by a Shapiro-Wilks test. Log10 transformation was conducted if data was deemed not normal distributed. Non-transformable not normal distributed data, due to zero values (RPD) were analyzed by using a two-way repeated measures analysis of variance (RM ANOVA). A two-by-six RM ANOVA was conducted to determine if an interaction and main effects of the two within factors, pad design (Full-pad × Half-pad) and time (Min 10 × Min 20 × Min 30 × Min 40 × Min 50 × Min60), on COP variability (SD, CV and SaEn) in AP and ML direction and RPD were present. A paired sample t-test for normally distributed data and Wilcoxon Signed-Rank test, for not normally distributed data were conducted to determine the effect of pad design on pad rating.

All two-way RM ANOVA's were tested for outliers by the examination of studentized residuals. Paired samples t-test was tested for outliers by inspection of boxplot. Likewise, all tests were checked for the assumption of sphericity. If assumptions were violated, a Greenhouse-Geisser correction was applied (ε). Post hoc test with Bonferroni correction was conducted when main effects were present. Repeated measures of subsets of variables, similarly to running a one-way RM ANOVA test, was applied if interaction of the two within factors were detected to determine simple main effects of the within

Table 3.1: Statistical results of effects of pad-design, time and interaction of pad×time on the dependent variables; standard deviation of center of pressure (SD of COP) in AP and ML direction, coefficient of variation of center of pressure in AP and ML direction (CV of COP), sample entropy of center of pressure (SaEn of COP) in AP and ML direction, and RPD at the ischial tuberosities (RPD_{IT}) and crotch (RPD_{Crotch}) area.

Variables	Pad-design		Time		Pad×Time	
SD of COP_{AP}	$F_{1,8=.010}$	p = .924	$F_{5,40 = 3.013}$	p = .021	$F_{1.981,15.846=1.620}$	p = .229, ε = .396
CV of COP_{AP}	$F_{1,8=.016}$	p = .903	$F_{2.502,20.016=.896}$	p = .444	$F_{1.566,12.734=1.344}$	p = .288
SaEn of COP_{AP}	$F_{1,8=.341}$	p = .575	$F_{5,40=1.796}$	p = .136	$F_{5,40=1.199}$	p = .327
SD of COP_{ML}	$F_{1,8=1.428}$	P = .266	$F_{5,40=1.433}$	P = .234	$F_{5,40=.701}$	p = .626
CV of COP_{ML}	$F_{1,8=2.501}$	p = .152	$F_{5,40=.248}$	p = .938	$F_{5,40=1.398}$	p = .246
SaEn of COP_{ML}	$F_{1,8=1.074}$	p = .330	$F_{5,40=1.256}$	p = .302	$F_{5,40=1.895}$	p = .117
RPD_{IT}	$F_{1,13=1.930}$	p = .129	$F_{1.328,17.121=17.267}$	p < .0005, ε = .266	$F_{1.357,17.638=.697}$	p = .458, ε = .271
RPD_{Crotch}	$F_{1,13=.056}$	p = .817	$F_{1.309,17.017=17.606}$	p < .0005, ε = .262	$F_{1.451,18.868=.195}$	p = .964, ε = .290

F = F-statistic, P = alpha level (p < 0.05), ε = Sphericity with Greenhouse-Geisser correction.

subject factor ‘pad’ at every within subject factor ‘time point’.

3 Results

A total of 14 participants were included in the study. However, technical problems caused discrepancy in dependent variable proportion prompting a total of nine participants with all dependent variables (pressure- and perceived discomfort data) intact, while five participants conducted the sessions without pressure measurements. No significant two-way interactions were found for any of the variables (Table 3.1). Mean and standard deviation of all variables at every time point for both pads are presented in table 3.3.

3.1 Main Effect of Padding on the Variability of Center of Pressure, the Rate of Perceived Discomfort, and Pad Rating

No main effects of pad on SD, CV and sample entropy of COP were detected (Table 3.1). Likewise, no significant main effect of pad design on RPD at the ischial tuberosities or crotch area were detected (Table 3.1). However, descriptive statistics of the localized crotch RPD (Table 3.2) showed tendencies towards similarities as well as differences in RPD in the localized crotch areas (Fig. 3.1) between the two pad designs. Pad designs elicited similar RPD with respectively a summed mean of 7.0 cm in the full-pad and 6.8 cm in the half-pad (Table. 3.2).

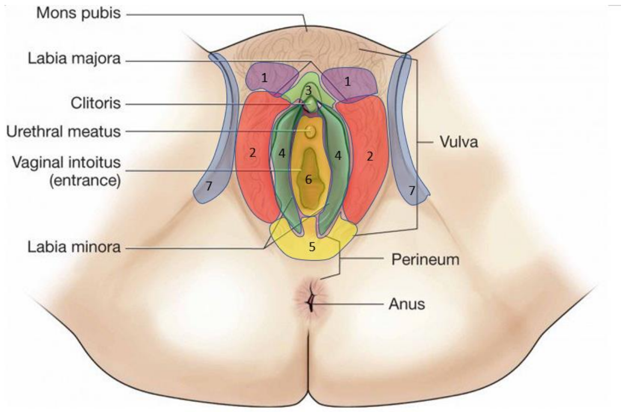

Figure 3.1: Localized crotch areas. Each area defined by number.

Table 3.2: Mean and percentage distribution of every localized crotch RPD of all participants (N=14) over all time points. Localized area is defined by number and presented in figure 3.1

		Full-Pad		Half-Pad	
Nr.	Area	Mean (cm) and Percentage Distribution (%) of localized Crotch RPD			
1	Skin area above Labia Majora	0.7	10.5%	1.3	19.6%
2	Labia Majora	2.2	31.7%	2.3	33.5%
3	Clitoris and surrounding skin area	0.9	12.1%	1.4	21.0%
4	Labia Minora	1.3	18.2%	0.7	10.1%
5	Skin of the perineum	0.2	2.2%	0.0	0.0%
6	Vaginal Introitus	1.4	19.9%	0.6	8.9%
7	Boarder of the perineum and medial surface of the thigh	0.4	5.4%	0.5	7.0%
	Sum of Mean	7.0	100%	6.8	100%

Table 3.3: Dependable variables: SD = standard deviation, COP = center of pressure, CV = coefficient of variation, SaEn = Sample Entropy, RPD = Rated Perceived Discomfort. $p \leq 0.05$. [a] Significantly different main effect from Min 10, [b] Significantly different main effect from Min 20, [c] Significantly different main effect from Min 30, [d] Significantly different main effect from Min 40.

	Full-Pad - SD, CV, and Sample Entropy of COP (N=9), RPD and Rating of Pad (N=14)						Half-Pad - SD, CV, and Sample Entropy of COP (N=9), RPD and Rating of Pad (N=14)					
Variables	**Min 10**	**Min 20**	**Min 30**	**Min 40**	**Min 50**	**Min 60**	**Min 10**	**Min 20**	**Min 30**	**Min 40**	**Min 50**	**Min 60**
^{N}SD of COP_{AP} (cm)	0.18±0.09	0.23±0.12	0.25±0.11	0.29±0.16	0.27±0.15	0.29±0.15	0.25±0.15	0.23±0.11	0.25±0.08	0.3±0.14	0.23±0.1	0.24±0.09
^{N}CV of COP_{AP} (%)	63.07±12.96	69±11.5	70.63±6.13	59.72±18.09	72.88±14.98	65.99±20.93	75.66±26.29	67.07±10.59	71.09±14.82	68.62±13.17	77.15±6.14	63.62±15.83
^{N}SaEn of COP_{AP}	0.82±0.12	0.78±0.09	0.74±0.07	0.7±0.13	0.71±0.09	0.66±0.1	0.74±0.18	0.74±0.1	0.71±0.21	0.65±0.12	0.73±0.12	0.74±0.18
^{N}SD of COP_{ML} (cm)	0.27±0.18	0.31±0.2	0.26±0.14	0.26±0.1	0.3±0.14	0.2±0.06	0.35±0.17	0.25±0.07	0.31±0.11	0.31±0.09	0.25±0.11	0.27±0.07
^{N}CV of COP_{ML} (%)	66.4±8.18	72.6±15.35	71.17±11.74	66.47±8.27	70.94±10.44	68.05±18.6	73.41±11.42	61.04±6.82	65.33±8.78	68.66±9.57	63.57±6.11	69.65±10.69
^{N}SaEn of COP_{ML}	0.55±0.09	0.49±0.16	0.54±0.16	0.57±0.08	0.52±0.11	0.6±0.08	0.43±0.11	0.53±0.1	0.51±0.11	0.52±0.13	0.55±0.13	0.54±0.12
RPD_{IT} (cm)	0.43±0.56	0.66±0.85	1.1±1.25	1.56±1.65^{b}	2.34±2.13^{abcd}	2.5±2.25^{abcd}	0.81±1.26	1.26±1.53	1.79±2.03	2.33±2.48^{b}	3.27±3.1^{abcd}	3.55±3.23^{abcd}
RPD_{Crotch} (cm)	0.61±1	1.04±1.41	1.76±2.08^{a}	2.88±2.82^{ab}	3.59±3.16^{abc}	3.71±3.29^{abcd}	0.86±1.24	1.34±1.88	1.86±2.2	2.75±2.83	3.59±3.43	4.01±3.72
Rating Pad	6.6±2.2						6.1±3					

Area two (Labia Majora) elicited similar intensity of RPD (2.2 cm (31.7%) in full-pad vs. 2.3 cm (33.5%) in half-pad, while area six and area four called for the greatest tendency of difference in the two designs, with respectively an RPD of 1.4 cm (19.9%) in the full-pad and 0.6 cm RPD (8.9%) in the half-pad in area four, and an RPD of 1.3 cm (18.2%) in the full-pad and 0.7 cm RPD (8.9%) in the half-pad in area six (Table 3.2).

Lastly, no significant difference between the liking of the two pads was detected ($t(13) = .645$, $p = .530$). Participants rated the full-pad and half-pad similar points (Table 3.3).

3.2 Effect of Time on the Variability of the Center of Pressure and the Rate of Perceived Discomfort

A main effect of time on COP in AP direction (Table 3.1). However, post hoc analysis with Bonferroni correction did not find any significant difference between time points. A main effect of time on RPD at both the ischial tuberosities and crotch area was detected (Table 3.1).

A post hoc analysis with Bonferroni adjustment revealed a statistically significant increase of~2.2 cm RPD at the ischial tuberosities from Min 10 to Min 50 ($p = .012$),~2.4 cm RPD from Min 10 to Min

60 (p = .009),~1.0 cm RPD from Min 20 to Min 40 (p = .031),~1.8 cm RPD from Min 20 to Min 50 (p = .008), ~2.1 cm RPD from Min 20 to Min 60 (p = .008),~1.4 cm RPD from Min 30 to Min 50 (p = 0.008),~1.6 cm

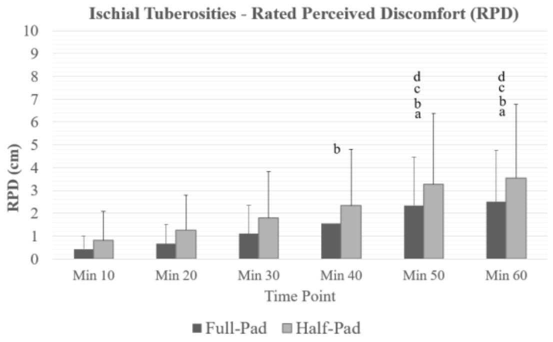

Figure 3.2: Mean and standard deviation of RPD at the ischial tuberosities. $p \leq 0.05$. [a] Significantly different from Min 10, [b] Significantly different from Min 20, [c] Significantly different from Min 30, [d] Significantly different from Min 40.

RPD from Min 30 to Min 60 (p = .008),~ 0.7 cm RPD from Min 40 to Min 50 (p = .006), and ~1.1 cm RPD from Min 40 to Min 60 (p = .016) (Fig. 3.2).

Similarly, a main effect of time on crotch RPD was detected (Table 3.1). A post hoc analysis with Bonferroni adjustment revealed a statistically significant ~1.1 cm increase of RPD in the crotch area from Min 10 to Min 30 (p = .028),~2.1 cm RPD from Min 10 to Min 40 (p = .009),~2.9 cm RPD from Min 10 to Min 50 (p = .006), ~3.1 cm RPD from Min 10 to Min 60 (p = .005), ~1.6 cm RPD from Min 20 to Min 40 (p = .027), ~2.4 cm RPD from Min 20 to Min 50 (p = .016), ~2.7 cm RPD from Min 20 to Min 60 (p = .015), ~1.8 cm RPD from Min 30 to Min 50 (p = .046), ~2 cm RPD from Min 30 to Min 60 (p = .030), and ~1 cm RPD from Min 40 to Min 60 (p = .026) (Fig. 3.3).

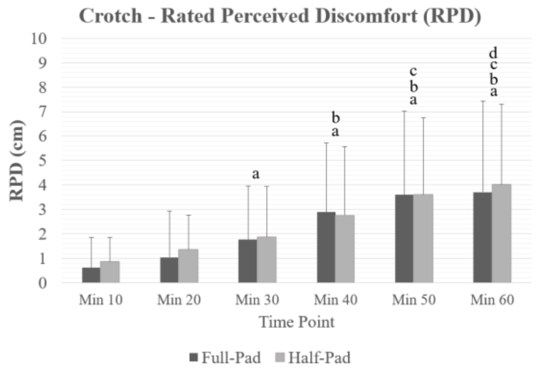

Figure 3.3: Mean and standard deviation of RPD at the crotch area. $p \leq 0.05$. [a] Significantly different from Min 10, [b] Significantly different from Min 20, [c] Significantly different from Min 30, [d] Significantly different from Min 40.

No main effect of time on the variability of center of pressure or RPD was detected (Table 3.1).

3.3 Effect of Session on the Rate of Perceived Discomfort and Pad Liking

A session order effect on RPD at the ischial tuberosities was detected with a statistically significant interaction (Table 3.4). Testing for simple main effects revealed significant differences between session one to session two at time point Min 20 ($F(1, 13) = 6.480$, p = .024), Min 40 ($F(1,13) = 8.971$, p = .010), Min 50 ($F(1, 13) = 7.813$, p = .015), and Min 60 ($F(1, 13) = 7.898$, p = .015). Post hoc analysis with Bonferroni correction revealed a decrease of ~0.9 cm RPD (p = .024) from session one

Table 3.4: Statistical results of session order effect on ischial tuberosity and crotch RPD.

Session order Effect on RPD				
Variables	**Pad**		**Pad×Time**	
RPD_{IT}	$F_{1,13=7.629}$	p = .016	$F_{5,65=2.845}$	p = .022
RPD_{Crotch}	$F_{1,13=4.093}$	p = .064	$F_{1.667,21.675=18.805}$	p = .191, ε = .333

F = F-statistic, P = alpha level (p < 0.05), ε = Sphericity with Greenhouse-Geisser correction.

to session two at Min 20, a decrease of ~1.5 cm RPD at session one to session two at Min 40 (p = .010), a decrease of ~1.8 cm RPD from session one to session two at Min 50, and lastly a decrease of ~ 2 cm RPD (p = .015) from session one to session two at Min 60.

The mean significant decrease (F(1, 13) = 7.629, p = .016) of RPD at the ischial tuberosities from session one (~ 2.4 cm RPD) to session two (~ 1.2 cm RPD), as determined by main effects in the two-way RMANOVA, was ~1.2 cm.

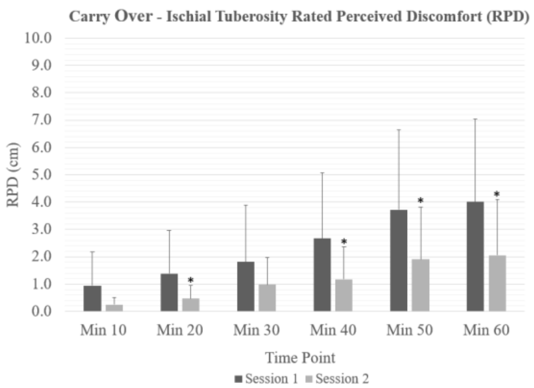

Figure 3.4: Carry over effect of session on RPD. $p \leq 0.05$. * Significantly different from Session one at same time point.

Pad liking rating was not affected by any main session order effect (t(13) = 1.961, p = .072). Pads tested in session one gained a mean rating of 5.7±2.5, while pads tested in session two gained a mean rating of 7.1±2.6.

4 Discussion

In the present study, effects of pad design on COP variability, as assessed by SD of COP and sample entropy and RPD and BPDS at the ischial tuberosities and crotch area, were investigated during one hour of ergometer cycling. Contrary to the hypothesis, no significant difference of pad and time interaction on the variability of center of pressure or RPD was detected. As expected, a significant increase of RPD with time was detected. Finally, an effect of session order was detected.

4.1 Effect of Pad

As no differences in RPD between pad-designs in the crotch area were detected the necessity of padding in the crotch area should be questioned. The presence of padding apparently does not influence the perception of discomfort in the crotch area, but arguably increase the risk of increased thermal insulation. As temperature and moisture formation have been associated with skin degeneration (Bergstrom, 2005; Wu et al., 2006) and increased friction (Gerhardt et al., 2008) it is presumably favorable to abstain from excessive padding in the crotch area, decreasing the risk of skin degeneration. Marcolin et al. (2015), examining the effect of three different cycling shorts pad designs and thicknesses on pressure *reduction* and subjective ranking of the pads, interestingly found similar contradictory effects of pad design on discomfort and pressure protection, with the pad design with the least protection of pressure receiving the most positive comfort evaluation. Meanwhile, the absence of difference in rated liking of the pad designs in the present study is consistent with the absence of difference in RPD and attest to a somewhat association between discomfort and rated linking of pad design.

However, subdivision RPD of the crotch area displayed a tendency towards both similarities and differences in RPD in localized crotch areas between the two pad designs, with a tendency of most notable RPD difference in area six and area four. For both pad design, area two elicited a tendency of the most discomfort. For the half pad, area six and area four showed a tendency towards less discomfort, as compared to the full-pad. These findings may imply that even though no significant difference between overall RPD measures between pad designs were found, the pad design may possibly have an influence on the area of discomfort.

Interestingly, the half-pad displayed a tendency towards more discomfort at the ischial tuberosities, as compared with the full-pad, even though there was no difference in posterior design of the pad, while discomfort in the crotch area was closely similar between the two designs throughout all time points (Fig. 3.2). These tendencies may suggest an effect of the absent crotch padding, causing changes in pelvic tilt to ease the contact with the crotch area, causing greater discomfort at the ischial tuberosities. In general, even though the participants were restricted by hand position, changes in pelvic and trunk motion is still possible, enabling the participant to change position on the saddle during the test, while difference in saddle position across participants may also have influenced ischial tuberosity and crotch discomfort, causing large deviations of RPD.

4.2 Effect of Time

The results displayed an expected temporal increase of discomfort (Zhang et al., 1996) during the one-hour cycling for both the ischial tuberosity area and the crotch area (Fig. 3.2 and 3.3). However, none of the pad designs elicited any effect on the variability of the center of pressure between time points. The lack of temporal influence on COP variability, as detected in Soendergaard et al. (2010), may derive from the experimental setup and time to discomfort (Lueder, 1983), with the present study investigating the COP variability during dynamic pedaling during one hour, while prior sitting behavior research of discomfort and COP variability have been conducted during comparatively static conditions, as e.g. long term driving for at least two and a half hour (Hermann, 2005), chair sitting for 100 minutes (Vergara and Page, 2002), seated video display unit operation for two hours (Fenety and Walker, 2002) and static seating without backrest and/or armrest for 96 minutes (Søndergaard et al., 2010).

Both presumable insufficient time to discomfort and the oscillating pressure distribution of pedaling (Bressel and Cronin, 2005; Potter et al., 2008; Wilson and Bush, 2007) may impede detectable micro movements by COP variability. Moreover, previous studies of COP variability and regularity have been conducted on musculoskeletal discomfort, i.e. discomfort in the lumbar region (Søndergaard et al., 2010; Vergara and Page, 2002) or whole body musculoskeletal discomfort (Fenety and Walker, 2002), while the present study evaluate soft tissue discomfort in the perineum. Type and location of discomfort may elicit different postural control strategies, why COP variability and regularity may not generate similar patterns of strategy as when musculoskeletal discomfort is present.

4.3 Effect of Session

Even though extended experimental precautions (blinded counterbalanced randomization) was conducted, the experiment elicited a session order effect of ischial tuberosity RPD. All participants were experienced cyclists accustomed to stationary cycling and posterior pad design in both pads were similar. However, the unpadded saddle presumably resulted in enhanced discomfort, such a carry-over effect of decreased discomfort from session one to session two was detected (Fig. 3.4). The carry over effect may imply that the ischial tuberosities are more prone to adaption of discomfort, as opposed to the crotch area. Moreover, the session order effect arguably expresses an effect of padding on discomfort perception, contrary to the speculations of Sequenzia et al. (2016), who proposed saddle geometry to be of greater importance than saddle padding.

4.4 Methodological Considerations

Analysis of static and dynamic force values prompted questionable pressure measurements and pressure mat reliability. The pressure mat exhibited drift, with increasing force values over time. With offset correction and normalization to body weight, force values displayed a mean increase of 15% from min 10 to min 60 in session one, and 9% in session two from min 10 to min 60. Most concerning, the pressure mat showcased force measures that were up to 50% greater than body force. By assigning the same work rate to all participants and normalizing to body weight, while prescribing a cadence of 80±5 rpm, all precautions were taken with regard to force measures (Bressel and Cronin, 2005). Based on the above findings, it was decided to leave out absolute pressure measurements.

Unfortunate technical problems with the pressure mat caused a reduction in sample size from 14 to nine participants, why the strength of a pair-wise design turned out to become a weakness. The reduced sample size for pressure measurements may have caused a type II error, causing failure in rejecting the null hypothesis (Banerjee et al., 2009). Similarly the nature of RPD by VAS is highly individual, dependent on prior experience and the concurrent psychological state of mind of the participant (Vink, 2005), arguably increasing the risk of outliers. Likewise, insufficient sample size may also have caused skewed data. A greater sample size may have distributed the data normally, reducing the chance of a type II error as well as enhanced the statistical power. Additionally, the present carry over effect may have been negated with an extended minimum period between session one and session two.

Future studies are warranted to investigate the effect of different padding geometries, thicknesses and densities on pressure distribution and discomfort in the crotch area in female cyclists. Likewise, effects of padding on pressure distribution and discomfort on different kinds of saddles (standard, grooved, and cut-out) is also warranted as differences in saddle geometry may affect the effect of cycle shorts padding, due to differences in pelvic tilt (Bressel and Larson, 2003). Additionally, temperature and moisture reduction may be of interest in the aim to establish discomfort and injury prevention in crotch area in female cyclists during cycling. Reduced padding in the crotch area may be preferable in terms of decreased generation of temperature and humidity, suspected to cause skin degeneration (Bergstrom, 2005; Gerhardt et al., 2008; Wu et al., 2006). Lastly, but maybe the most warranted - it may be of great interest to determine the cause of discomfort. Does discomfort occur as a result of pressure, or as a result of skin degeneration?

5 Conclusion

The present study was the first study to systematically design, produce and test the effect of cycling shorts padding on pressure distribution and discomfort in the crotch area in female cyclists. Contrary to the hypothesis, pad-design elicited no effect on the variability of COP in AP and ML direction nor ischial tuberosity- or crotch RPD, suggesting a low effect padding in the crotch area. Session order effect may however suggest an adaption to discomfort at the ischial tuberosities, while crotch discomfort was less adaptable.

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