

The Biomechanical and Perceptual Impact of Breast Support during Riding and Running in Female Equestrians

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Abstract

Popular among women, equestrian sport is the only sex-integrated Olympic sport, relying on interspecies communication between horse and rider. Despite extensive breast research in sport, equestrian research is limited. This study investigated the impact of bras on breast movement, comfort, and pain; rider position and asymmetry; and compared breast movement and pain in riding versus running. Participants ($n = 21$) rode a Racewood™ Equine Simulator (ES) in walk, trot, and canter and ran on a treadmill (TM) in four breast support conditions: everyday (EB), encapsulation sports bra (ESB), combination sports bra (CSB), and bare-breasted (BB). Markers were tracked by a Qualisys motion capture system, and relative breast displacement (RBD) in TM and ES was calculated, along with rider position during ES. Exercise-induced breast pain (EIBP) and bra comfort were measured on 0–100 visual analogue scales, and a survey on bra performance and aesthetics was completed. TM caused the highest EIBP (mm) ($\bar{x} = 67.25$, $P < 0.001$) and RBD (cm) ($\bar{x} = 5.56$, $P < 0.001$) in BB. A moderate positive association ($r_s(19) = 0.428$, $P < 0.001$) was observed between EIBP and RBD, both of which were reduced by ESB (EIBP $P < 0.001$; RBD $P < 0.002$) and CSB (EIBP $P < 0.001$; RBD $P < 0.001$) in trot and TM. In trot, torso position improved in ESB ($Z = -3.841$, $P < 0.001$) and CSB ($Z = -3.806$, $P < 0.001$) compared to EB, and riders were most symmetrical in ESB. Bra comfort and preferences were idiosyncratic. Bra type meaningfully influenced EIBP, rider position, and symmetry. Future larger, longitudinal, field-based studies are warranted.

Keywords

Rider performance; bra; breast pain; rider position; asymmetry

1. Introduction

Equestrianism is characterized as the only sex-integrated Olympic sport [1] with a female participant bias at all levels, and is novel, involving more than one species. In equestrian activities in the United Kingdom (UK), 85% of regular horse riders are female, and 35% are over the age of 55 years [2]. Activity recommendations from the World Health Organization suggest adults should participate in at least 150

minutes of moderate-intensity exercise each week [3], yet only 50–60% of adults meet these guidelines and 30% when considering aerobic and resistance training [4]. Oxygen consumption levels during horse riding suggest a moderate intensity in female riders [5], and of 1248 respondents, 48% indicated horse riding was their only exercise activity [6]. It is therefore important to encourage female participation in horse riding to avoid sedentary lifestyles, and barriers to female participation

in equestrianism should be addressed, particularly as, when considering female physical activity in the general population, 33% do not meet physical activity guidelines [7].

Horse riding requires a complex interaction between two species [8] and is primarily achieved through the application of tactile cues. Miscommunication can result in negative outcomes for horse welfare and rider safety [9]. Most equestrian research, until relatively recently, has focused on the performance and welfare of the horse, often excluding the impact of the rider within this dyad. Optimal rider performance has attracted increasing research interest in recent years [10], particularly rider asymmetry [11]. A lack of symmetry in the rider's position may negatively impact their ability to effectively apply the tactile cues required to control the horse [12], decreasing clarity of interspecies communication. Many factors can impact rider position, such as pain [13], laterality [14], skill level [15], pelvis control [16], and sex [17]. Indeed, it is suggested [17] that female equestrians are at a biomechanical disadvantage as they demonstrate greater pelvic obliquity, trunk lean and shoulder tilt than their male counterparts. Should female-specific challenges such as inappropriate breast support add to this propensity for positional asymmetry, given the high proportion of female equestrian participants, a significant challenge to equine welfare and rider safety could be prevalent.

There is a range of barriers to physical activity specific to female participants such as the menstrual cycle [18,19] and body image [20,21], but breast-related discomfort in particular is frequently cited as a key deterrent to female sporting participation [7,22,23]. Breast and bra issues can limit participation in horse riding as well as negatively impact performance [24,25]. Many female athletes (44%) report exercise-induced breast pain (EIBP) and associated frictional injuries caused by their sports bras [22]. Highly supportive bras can cause discomfort [26], which often deters women from wearing adequate breast support [27]. Sports bras, while essential for mitigating breast movement during physical activity, are often designed based on research findings from a younger demographic [23]. In equestrianism, career longevity [1] may impact bra suitability, as career activity can continue beyond that expected of female athletes in other sports. Female horse riders may face novel challenges in finding appropriate breast support as everyday bras, the second most worn for horse riding [25], are among the least effective in controlling breast displacement, a significant contributor to EIBP [28]. The rider must also absorb large movements of the horse and often does not consider herself an "athlete," with the fitness of the horse taking priority [8]. It was found that only 56% of equestrian respondents considered themselves as physically fit [29], although 98% felt that fitness impacted their equestrian performance. Female equestrians may be unfamiliar with available sports bras or may find it challenging to find comfortable breast support due to the longevity of wear, like other physically active occupations [30].

Increased breast support reduces breast movement but often compromises comfort, and this discomfort does not always align with breast displacement or acceleration, indicating possible psychogenic influences [31]. Bras also affect shoulder kinematics, muscle activity, and proprioception

[32], which may influence rider performance. Horse riding involves substantial vertical motion that riders must absorb; without adequate support, this can lead to exercise-induced breast pain (EIBP). Around 40% of riders report EIBP, with 21% noting performance impacts [33]. Pain can limit performance by impairing postural control and reducing the clarity of tactile cues [34], which may compromise horse welfare [35] and rider safety [9]. Therefore, bras providing both effective support and comfort are essential for optimizing the horse-rider dyad [36]. In equestrian sports, where posture, precision and synchronicity are critical [37], excess breast motion can disrupt upper-limb and torso alignment [24], reducing communication clarity between horse and rider [38].

Wearing a suitable bra during physical activity can enhance performance by stabilizing breast motion and reducing associated pain [24]. Despite these practical benefits, the comfort provided by most commercially available bras remains inconsistent [37], particularly for the equestrian population [25]. Bra comfort perceptions are inherently user-dependent and change depending on the environment, activity, age, and season [39], suggesting that further investigation of bra comfort as well as efficacy is warranted during equestrian-specific activities. Most sports bras are designed for running activities, yet relative vertical breast displacement (RVBD) and EIBP in equestrians differ between equine gaits [24]. Due to these gait differences and because equestrian RVBD and EIBP differ from running measures, further investigation was warranted. In previous research investigating the impact of breast support on rider position [24], rider symmetry was not measured. Given the importance of rider symmetry to performance [12], this study aimed to investigate EIBP, relative breast displacement (RBD), rider position and symmetry, bra efficacy, and comfort during equestrian activities in three common bra types. A secondary aim was to compare RBD and EIBP during equestrian activity to treadmill running for this sample population.

2. Methods

Following institutional ethical approval (ETHICS2023-74), female equestrians ($n = 21$) were recruited who were experienced recreational horse riders, able to maintain balance in walk, trot and canter on a horse, and capable of running on a treadmill at ~ 2.5 meters per second (m/s). Participants were aged (mean $\pm$ SD) 40 (± 11) years, height 169.38 (± 5.82) cm, mass 66.48 (± 6.96) kg, with self-reported bra sizes ranging from a UK 32 to 38 band size and between B and FF cup size (Table 1). Prior to data collection, potential participants had been sent a detailed information sheet detailing the requirements of the data collection and returned a written consent form confirming they regularly completed the level of exercise required in the trials. As changes in breast tissue occur during pregnancy, breastfeeding, and post-surgical intervention [40], participants were excluded if currently pregnant, had breastfed within the previous year, or had undergone breast surgery. Prior to data collection, participants completed a 20-question online survey via MS Forms adapted from a previous study [24] to gather information on bra usage, equestrian activity, and physical activity habits. The survey included closed Likert scale questions and free-text responses. Bras were fitted to all participants according to professional best-fit criteria [41] and were an encapsulation style bra marketed as a horse riding bra (ESB) (padded,

underwired, 75% polyamide and 25% elastane, Berlei™), a combination running sports bra (CSB) (Ultimate Run Bra, 10% polyester, 81% polyamide and 9% elastane, Shock Absorber™) and an everyday bra (EB) (plain, non-padded, underwired T-shirt bra, made from 78% polyamide and 22% elastane; Marks & Spencer™).

2.1. Riding Trials (Equine Simulator)

Each participant completed a 120 s habituation on a Racewood™ Equine Event Simulator (Eaton, UK), comprised of 30 s at medium walk, 30 s at medium trot (sitting), 30 s at medium canter right, and 30 s at medium canter left [24]. Reflective markers (B&L Engineering Reflective Markers, Santa Ana, CA, USA; 9.5 mm sphere, base 17 mm hard plastic) were positioned on each nipple, over the bra when worn, the suprasternal notch and the back at the seventh cervical vertebra (C7), the eighth thoracic vertebra (T8), at 75% of the distance between these markers, and on the left and right anterior inferior aspect of the 10th ribs [42]. Markers were also placed on the acromion, lateral epicondyle of the distal humerus, radial styloid process, greater trochanter, lateral epicondyle of the distal femur, and lateral malleolus on both sides of all participants to assess rider position [24]. Further marker clusters were attached to the proximal and distal arm and leg segments (Figure 1).

Riding trials were completed in four breast support conditions: everyday bra (EB), encapsulation sports bra (ESB), combination sports bra (CSB), and bare-breasted (BB), randomly assigned except that the BB condition was completed last [24], in three equine gaits: medium walk, medium trot (sitting), and medium canter. Each riding trial was completed over 60 s, with the final 30 s captured for analysis, apart from the BB condition, for which only 30 s were required in each gait (due to the associated discomfort and exposed nature of this condition), all of which was recorded. Breast movement and rider position were captured using a Qualisys motion capture system (Qualisys AB, Gothenburg, Sweden) consisting of two Arqus 12 and six Miquis M3 infrared cameras sampling at 240 Hz, tracking passive reflective markers throughout the capture volume.

Directly after each breast support condition in each gait, participants rated their exercise-induced breast pain on a 100 mm Visual Analogue Score (VAS) from 0 mm (no pain) to 100 mm (extreme pain). Following all equine gaits in

each bra condition, bra comfort was also rated on a 100 mm VAS from 0 mm (extremely uncomfortable) to 100 mm (extremely comfortable).

2.2. Running Trials (Treadmill)

Following riding trials, Position markers were removed (Figure 1), and remaining marker placement was inspected for secure attachment. Each participant identified a comfortable running speed on the treadmill ($2.32 \text{ m/s} \pm 0.16$; range = 2.15–2.68 m/s), and individuals completed all running trials at their identified comfortable speed. Running trials were completed in the four breast support conditions in the same order randomly assigned during the riding trials and using the same protocol. On reaching their comfortable running speed, participants ran for 60 s, with the final 30 s captured for analysis. For BB trials, data were collected and analyzed for the first 30 s only to reduce breast discomfort in this condition. Breast movement was captured using a Qualisys motion capture system (Qualisys AB, Gothenburg, Sweden) consisting of seven Miquis M3 infrared cameras sampling at 240 Hz, tracking passive reflective markers throughout the capture volume.

Post-data collection, participants completed an online questionnaire (MS Forms) including closed multiple-choice questions to identify bra preference for different activities and open-ended free-text questions regarding their opinions of bra appearance, comfort, and suitability (Supplementary File 1).

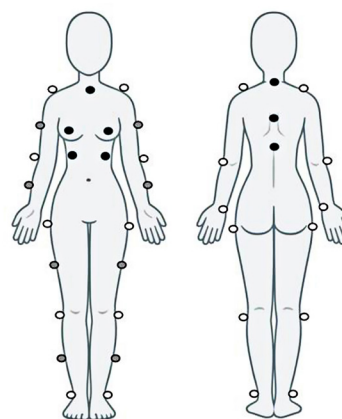


Figure 1: Marker and cluster placement – ● riding and running trials; ○ marker and ● cluster placement in riding trials only.

Table 1: Distribution of participant self-reported bra size (UK underband and cup size) ($n = 21$).

Underband (inches)	Cup size							Total
	B	C	D	DD	E	F	FF	
32		2						2
34	3	2	2	1			1	9
36	2	4	2					8
38					1		1	2
Total	5	8	4	1	1	0	2	21

2.3. Data Analysis

For riding and running trials, motion capture data were processed using Qualisys Track Manager (QTM; Qualisys AB, Gothenburg, Sweden). All marker trajectories were labeled and gap-filled within QTM, and kinematic variables of rider position and RBD were extracted for each gait and breast support condition. Data were filtered using a 6 Hz Butterworth filter and exported as CSV files for subsequent statistical analysis using IBM SPSS Statistics (Version 31; IBM Corp., Armonk, NY, USA). Five stride cycles were selected for analysis in each gait for each support condition. In equine gaits, the highest recorded point of the suprasternal notch determined the beginning of each stride cycle, and heel strike was utilized in treadmill running. A trunk coordinate system was defined with the origin at the midpoint between the left and right rib markers and the suprasternal notch [42]. Three-dimensional RBD displacement (cm) was calculated relative to the trunk using Microsoft Excel. The measures of LN and RN were not significantly different, so RN RBD was utilized and reported throughout. Angular data for knee and elbow angles were calculated from QTM (Figure 2). Mean knee and elbow angles were calculated during the symmetrical gait of trot, and range of motion (ROM) was established. Rider elbow and knee angles were then compared for right and left measures. Torso position was measured from the horizontal plane for torso angle dorsoventral (TADV) and torso angle mediolateral (TAML), with mean angles and ROM calculated in all gaits and breast support conditions.

Participants were grouped as small-breasted (< D cup) and large-breasted ($\geq$ D cup) for further analysis [24] to assess any impact of breast size on measured variables. Bra comfort and EIBP were obtained by measuring participant-recorded lines on the VAS, giving a value for each participant in each gait and breast support condition (mm) for each bra. Survey responses were exported from MS Forms to MS Excel for quantitative and qualitative analysis. Quantitative data were initially analyzed descriptively, and qualitative analysis was conducted following Braun and Clarke [43] guidelines for thematic analysis, and all qualitative results were reported following the Standards for Reporting Qualitative Research (SRQR) [44].

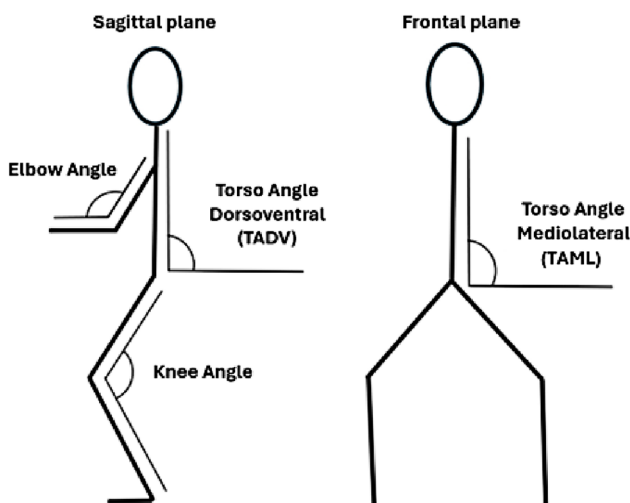


Figure 2: Rider position angles measured (TADV = Torso Angle Dorsoventral, TAML = Torso Angle Mediolateral).

2.4. Statistical Analysis

Data normality was assessed using the Shapiro-Wilk test prior to inferential analysis in IBM SPSS Statistics (Version 31; IBM Corp., Armonk, NY, USA). As the data did not meet the assumptions for parametric analysis, values are reported as medians and interquartile ranges (IQR = $Q_3 - Q_1$) throughout. Differences in EIBP and RBD across breast support conditions were assessed using Friedman tests with post-hoc pairwise comparisons using Wilcoxon signed-rank tests with a Bonferroni correction applied ($\alpha = 0.008$). Knee and elbow symmetry in trot for each participant was assessed using Bland-Altman plots, where perfect agreement = 0, and compared in the same manner. Further analysis of interactions between breast support conditions and breast size groups was conducted using linear mixed-effects models (LMMs) where data were continuous, and residuals were approximately normal. Spearman's rank-order correlation was used to assess the relationship between EIBP and RBD. The strength of correlations was interpreted as per Schober *et al.* [45], where correlation coefficients of 0.00–0.09 were considered negligible, 0.10–0.39 weak, 0.40–0.69 strong, and 0.90–1.00 very strong. Quantitative post-survey results were analyzed using chi-squared (χ^2) tests of independence to identify associations in bra choice between small- and large-breasted groups.

2.5. Thematic Analysis

As responses to open-ended questions from all participants completing the post-data collection survey regarding bra performance, fit and design, and bra appearance were relatively brief, analysis using a six-step, hybrid inductive-deductive thematic analysis was conducted [43]. Responses were initially coded by a member of the research team (L.C.), informed by the study aims and existing breast and bra literature [39,41]. The coding framework remained flexible to allow new codes to develop from the data where appropriate. Coding was reviewed by another member of the research team (V.L.), and any disagreement was discussed. No triangulation was required as agreement was reached by both researchers. Codes were refined and grouped into subthemes and higher-order themes to represent recurring patterns within participant responses, agreed upon by both researchers (L.C. & V.L.). The number of responses within each theme was calculated and used to identify the distribution of responses rather than the importance of each theme.

3. Results

Of the usable pre-data collection surveys ($n = 19$), 63% of participants engaged in horse riding more than once per month and 74% identified as 'leisure riders.' The median age at which bra wear began was 13 years. While 74% reported always wearing a bra, the remainder wore one only during specific physical activities. Only 16% had received a professional bra fitting in the previous year, 63% had been fitted more than one year previously, and 21% had never been fitted. For horse riding, 74% wore a sports bra, and the remainder wore an underwired everyday bra. Most respondents (63%) 'rarely' or 'never' noticed their bra while riding, while 37% 'sometimes' or 'always' noticed it. Bra-related discomfort and adjusting straps during riding were reported by 21%, and bras caused noticeable pain for 11%. Nearly half (47%) 'sometimes' experienced breast pain while horse riding, and 53% reported breast pain off-horse associated with

their menstrual cycle. Riding and running trials were completed by all participants ($n = 21$).

3.1. Exercise-Induced Breast Pain (EIBP)

Across all equestrian gaits, EIBP differed significantly between breast support conditions. BB produced the highest pain scores in walk ($\chi^2(3) = 16.523$, $P < 0.001$), trot ($\chi^2(3) = 36.708$, $P < 0.001$), and canter ($\chi^2(3) = 24.189$, $P < 0.001$). Post-hoc tests showed that in walk and canter, ESB and CSB significantly reduced EIBP compared with BB ($P < 0.008$), whereas EB did not. In trot, EB, ESB, and CSB significantly reduced EIBP relative to BB ($P < 0.001$ for all), and CSB further reduced EIBP compared with EB ($P = 0.004$), with full details of EIBP included in **Supplementary File 2**.

During treadmill running, EIBP was highest in BB ($\bar{x} = 67.25$, IQR = 30.3) and differed significantly across conditions ($\chi^2(3) = 56.045$, $P < 0.001$). All support conditions reduced EIBP relative to BB ($P < 0.001$). Additional post-hoc analysis showed lower EIBP in ESB ($Z = -3.064$, $P = 0.002$) and CSB ($Z = -3.604$, $P < 0.001$) compared with EB.

3.2. Relative Breast Displacement (RBD)

In the BB condition, LMMs fitted with gait (4 levels) and breast size group (2 levels) as fixed effects showed that vertical RBD (RBDZ) was significantly affected by gait ($F(3, 57) = 30.416$, $P < 0.001$) and breast size group ($F(1, 19) = 8.21$, $P = 0.01$), with no gait $\times$ breast size interaction. Dorso-ventral displacement (RBDY) was affected by gait ($F(3, 57) = 64.086$, $P < 0.001$), breast size ($F(1, 19) = 24.339$, $P < 0.001$), and a significant gait $\times$ breast size interaction ($F(3, 57) = 5.556$, $P = 0.007$). Mediolateral displacement (RBDX) was affected by gait ($F(3, 57) = 81.152$, $P < 0.001$), with no effect of breast size or interaction.

Across all breast support conditions, CSB produced the lowest RBDZ values in walk, trot, canter, and treadmill running (all χ^2 tests, $P \leq 0.04$). Percentage reductions in RBDZ were also greatest in CSB across all gaits (**Table 2**). Breast support significantly reduced RBDY in canter ($\chi^2(3) = 11.641$, $P = 0.009$) and treadmill running ($\chi^2(3) = 37.507$, $P < 0.001$), and reduced RBDX during running only ($\chi^2(3) = 32.426$, $P < 0.001$) (**Table 3**). Post-hoc Wilcoxon signed-rank tests ($\alpha = 0.008$) for all significant models are reported in **Supplementary File 2**.

Table 2: Relative breast displacement (cm). Bold indicates the lowest median displacement and highest percentage reduction in each gait; NR indicates no reduction (RBD = relative breast displacement, BB = bare-breasted, EB = everyday bra, ESB = encapsulation sports bra, CSB = combination sports bra).

Bra Type	Mediolateral (X) RBD		Dorsoventral (Y) RBD		Vertical (Z) RBD	
	$\bar{x}$ (IQR) X RBD (cm)	% Reduction from BB	$\bar{x}$ (IQR) Y RBD (cm)	% Reduction from BB	$\bar{x}$ (IQR) Z RBD (cm)	% Reduction from BB
Walk						
BB	0.77 (0.75)	NR	0.38 (0.53)	NR	2.28 (0.88)	NR
EB	0.57 (1.34)	25.97	0.33 (0.50)	13.15	2.15 (1.10)	5.7
ESB	0.92 (0.93)	NR	0.50 (0.69)	NR	2.01 (0.62)	11.84
CSB	0.83 (0.74)	NR	0.27 (0.48)	28.95	1.73 (0.96)	24.12
Trot						
BB	0.77 (0.85)	NR	0.62 (1.28)	NR	2.45 (1.31)	NR
EB	0.76 (0.68)	1.29	0.28 (0.48)	54.83	2.29 (1.66)	6.53
ESB	0.98 (0.79)	NR	0.28 (0.73)	54.83	1.88 (0.99)	23.26
CSB	1.04 (1.04)	NR	0.26 (0.40)	58.06	1.74 (1.08)	28.97
Canter						
BB	1.76 (1.97)	NR	0.56 (0.59)	NR	2.24 (1.65)	NR
EB	1.52 (2.87)	13.64	0.29 (0.28)	48.21	2.26 (1.61)	NR
ESB	1.05 (1.43)	40.34	0.39 (0.53)	30.35	2.28 (1.70)	NR
CSB	1.48 (1.41)	15.91	0.39 (0.65)	30.35	2.05 (1.56)	8.48
Treadmill Running						
BB	5.94 (2.93)	NR	3.83 (2.49)	NR	5.57 (2.35)	NR
EB	4.68 (3.43)	21.21	2.61 (2.37)	31.85	3.47 (2.24)	37.7
ESB	4.37 (2.57)	26.43	2.15 (1.93)	43.86	2.61 (1.57)	53.14
CSB	3.97 (2.28)	33.16	1.59 (2.09)	58.48	2.13 (1.53)	61.76

Table 3: Median (IQR) Agreement of right and left elbow and knee (o = perfect symmetry) in trot. Bold indicates the breast support condition with the best symmetry measure (BB = bare-breasted, EB = everyday bra, ESB = encapsulation sports bra, CSB = combination sports bra, $\bar{x}$ = median, IQR = interquartile range).

Bra type	$\bar{x}$ (IQR) agreement
Elbow	
BB	4.5 (6.38)
EB	5 (8.63)
ESB	2 (6.6)
CSB	5.5 (6.1)
Knee	
BB	7.25 (11.25)
EB	7 (11.25)
ESB	4 (10)
CSB	5.5 (10.75)

LMM analysis showed no effect of breast size group and no breast support $\times$ breast size interaction for symmetry outcomes.

3.3. Relationship Between EIBP and RBD

Across all breast support conditions and gaits, EIBP was moderately and positively correlated with RBDZ ($r_s(19) = 0.428$, $P < 0.001$) and weakly to moderately correlated with RBDX ($r_s(19) = 0.377$, $P < 0.001$) and RBDY ($r_s(19) = 0.355$, $P < 0.001$).

3.4. Rider Position

3.4.1. Symmetry (Elbow and Knee Measures)

In the symmetrical gait of trot, Bland-Altman graphs identified the breast support condition producing the smallest mean difference between right and left limb angles (mean bias = 0 indicates symmetry). Across participants, ESB most frequently resulted in the lowest mean bias values for both elbow and knee (Table 3). Friedman tests showed significant effects of breast support on elbow symmetry ($\chi^2(3) = 16.797$, $P < 0.001$) and knee symmetry ($\chi^2(3) = 31.629$, $P < 0.001$) in trot. Post-hoc Wilcoxon tests indicated greater symmetry in ESB than EB for both elbow ($P = 0.008$) and knee ($P < 0.001$) measures, and CSB further improved elbow symmetry compared with ESB ($P < 0.001$).

In canter, knee ROM asymmetry differed significantly between breast support conditions ($\chi^2(3) = 31.371$, $P < 0.001$). EB, ESB, and CSB each reduced knee ROM asymmetry compared with BB ($P < 0.001$). No significant differences in ROM or mean knee and elbow symmetry were observed between breast support types in walk.

3.4.2. Torso Position

Torso mean angles did not differ significantly across breast support conditions in walk or canter. In trot, a significant effect of breast support on torso angle dorsoventral mean (TADV) was identified ($\chi^2(3) = 41.971$, $P < 0.001$). Post-hoc tests showed that ESB and CSB produced significantly greater (more upright) torso mean angles than BB and EB

(ESB: $Z = -3.841$, $P < 0.001$; CSB: $Z = -3.806$, $P < 0.001$). No significant difference was found between ESB and CSB, or between EB and BB (Figure 3). Torso ROM did not differ significantly between conditions in any gait.

3.5. Post-Survey Responses

Seventeen participants completed the post-trial survey. Descriptive differences were observed in perceived strap comfort, band comfort, and ease of application (Figure 4), although none reached statistical significance. For riding, 41.7% selected CSB and 35.3% ESB as their preferred bra, while 23.5% selected none of the trial bras. For running, 58.9% chose CSB, 11.8% ESB, and 29.4% none; no participants selected EB for either activity. Chi-squared tests showed no differences in preferences or comfort ratings between breast size groups.

Thematic analysis [43] identified four themes relating to bra performance and design (Figure 5) and five themes related to appearance (Figure 6). Comments highlighted variation in preferred strap design, comfort, ease of fastening, color suitability for equestrian competition clothing, and perceptions of support during sitting trot.

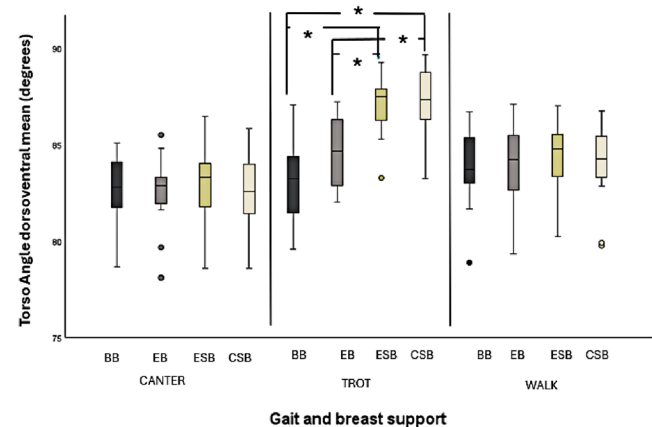


Figure 3: Box-and-whisker plot of Torso Angle dorsoventral mean (TADV) (degrees) by breast support condition in walk, trot, and canter. Boxes joined by a line and asterisks (*) differ significantly at $P < 0.001$. (BB = bare-breasted, EB = everyday bra, ESB = encapsulation sports bra, CSB = combination sports bra) (o indicates outliers).

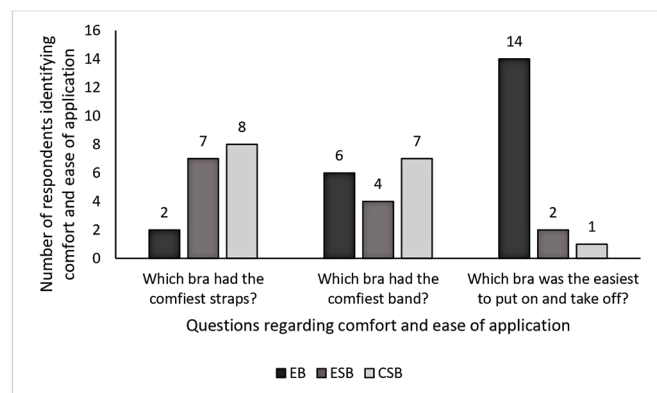


Figure 4: Clustered column chart of bra comfort and application questions (EB = everyday bra, ESB = encapsulation sports bra, CSB = combination sports bra) ($n = 17$).

Higher Order Theme	Sub Theme	Example Quotes
Breast Support	Good Breast Support (ESB 4, CSB 5, EB 1)	ESB – “Loved the riding bra (ESB) comfort and support offered!”, “Did a good job support wise” CSB – “Very supportive and reduced movement in both conditions”, “It was supportive” EB – “was supportive”
	Poor Breast Support (ESB 4, CSB 0, EB 4)	ESB – “I didn’t feel as though it gave me as much support as the running bra (CSB)”, “it didn’t provide the support I was expecting especially in trot” EB – “can’t see it would support”, “didn’t feel very supportive”, “like your average everyday bra”
Bra Comfort & Fit	Good Comfort & Fit (ESB 6, CSB 7, EB 3)	ESB – “really comfortable”, “Very comfortable”, “Loved the riding bra (ESB) comfort” CSB – “a very comfortable sports bra and would consider buying”, “would wear for running and riding” EB – “comfortable bra”, “I liked the way it felt”
	Poor Comfort & Fit (ESB 3, CSB 3, EB 1)	ESB – “uncomfortable when exercising”, “It wasn’t so comfortable”, “little uncomfy in the band” CSB – “can wear for exercise but not for long time”, “Quite uncomfortable to wear” EB – “high under the arms”
Bra Strap Design	Good Strap Design (ESB 2, CSB 2, EB 1)	ESB – “no strap slip off the shoulder”, “comfy straps” CSB – “double straps at the back”, “the straps don’t fall down my shoulders whilst out riding/working” EB – “doesn’t pull on shoulders”
	Poor Strap Design (ESB 4, CSB 0, EB 0)	ESB – “the straps started to fall off my shoulders”, “fall down whilst riding at some point and are quite annoying to keep having to adjust back into the right position”
Bra Fixings & Fittings	Good Fixings & Fittings (ESB 1, CSB 0, EB 0)	ESB – “is more like an everyday bra”
	Poor Fixings & Fittings (ESB 2, CSB 6, EB 0)	ESB – “I do not like riding in underwired bras from a safety perspective”, “I prefer absence of underwire” CSB – “Too many fixings for me”, “It would be a nightmare to put on and take off alone”

Figure 5: Thematic tree of post-survey responses to free-text answers regarding bra performance, fit, and design (ESB = encapsulation sports bra, CSB = combination sports bra, EB = everyday bra).

Higher Order Theme	Sub Theme	Example Quotes
Colour	Good Colour (ESB 5, CSB 1, EB 2)	ESB – “would be suitable for a competition setting”, “good colour for under a competition shirt” CSB – “neutral colour” EB – “wearable under any colour top”
	Poor Colour (ESB 1, CSB 4, EB 0)	ESB – “colours could be more exciting” CSB – “it’s not my colour”, “horrible”, “would show under a shirt”, “wouldn’t normally go for such bright colours”
General Appearance	Good Appearance (ESB 11, CSB 9, EB 3)	ESB – “very flattering”, “looks nicer than a sports bra”, “substantial but was not ugly” CSB – “fine, no issues, would wear”, “its appearance is normal for this sort of bra” EB – “fairly average”, “looked attractive”
	Poor Appearance (ESB 4, CSB 2, EB 0)	ESB – “a bit bland”, “visually not very appealing”, “doesn’t look like the usual sort of bra I would go for” SB – “not as nice as the riding bra (ESB)”, “this was a bit more bulky than the other bras” EB – “cup shape didn’t do a lot for the shape of my breasts”
Material	Good Material (ESB 4, CSB 1, EB 4)	ESB – “it was a nice material”, “soft”, “material was nice”, “material that doesn’t cause skin breakout” CSB – “the material felt more lightweight than the other two bras tried” EB – “no nipple issues”, “nice feel”, “similar to the riding bra (ESB)”
	Poor Material (ESB 1, CSB 1, EB 0)	ESB – “I am not sure that would do well with sweat” CSB – “it was a huge amount of material around the chest, and I didn’t feel it supported my boobs as the actual cups were quite thin”
Bra Fixings	Good Fixings (ESB 0, CSB 1, EB 0)	CSB – “I normally wear running bras that I have to pull over my head, so the straps is a much easier option”
	Poor Fixings (ESB 1, CSB 3, EB 1)	ESB – “but potentially tricky to get on and off by yourself” CSB – “didn’t like the appearance two fixings isn’t for me!”, “its design would not allow me to put it on myself without a struggle”, “I also didn’t like the second restrictive clip at the top of my back”
Design Features	Good Design (ESB 1, CSB 2, EB 1)	ESB – “good size straps” CSB – “look good if exposed through running vest”, “Just about avoided the monoboo” EB – “doesn’t create ‘caterpillar’ effect on the side”
	Poor Design (ESB 2, CSB 1, EB 0)	ESB – “not good coverage for nipples so would affect likelihood to wear it”, “underwire” CSB – “less comfortable than the riding bra (ESB)”

Figure 6: Thematic tree of post-survey responses to free-text answers regarding bra appearance (ESB = encapsulation sports bra, CSB = combination sports bra, EB = everyday bra).

4. Discussion

This is the first study to investigate the combined effects of breast support on breast biomechanics, EIBP, rider position, and bra suitability during equestrian exercise and the first to compare breast motion and pain between equestrian simulator gaits and treadmill running within the same sample. By integrating biomechanical, perceptual, and qualitative data, this research provides a comprehensive assessment of how breast support influences both comfort and rider performance, highlighting the need for activity-specific breast support solutions in equestrian sport.

4.1. Exercise-Induced Breast Pain (EIBP)

Consistent with previous findings, treadmill running induced the highest levels of EIBP across all breast support conditions, likely due to the greater vertical accelerations of the torso characteristic of running [24,33]. Sitting trot was the equestrian gait inducing the most breast pain, consistent with previous research [24]. While increased breast size is often linked to EIBP [46], the absence of a significant breast size effect in this study is likely reflective of the comparatively small proportion of large-breasted riders (38.1%), unlike previous surveys where over half of respondents reported D+ cup size [25]. Informal feedback suggested that some large-breasted riders were hesitant to participate due to anticipated discomfort during running trials, potentially contributing to under-representation of large-breasted riders in this sample. Future work should consider recruitment strategies specifically designed to encourage large-breasted equestrian participation to ensure a more representative sample. Higher levels of breast support (ESB and CSB) consistently reduced EIBP across equestrian gaits and treadmill running in line with the established association between reduced breast displacement and reduced pain [23,24]. These findings reinforce the importance of appropriate bra selection and wear for equestrians to mitigate pain and maintain comfort when horse riding.

4.2. Relative Breast Displacement (RBD) and Exercise-Induced Breast Pain (EIBP)

Vertical breast displacement (RBDZ) was greatest in the BB condition and was significantly influenced by breast size and gait. The CSB condition consistently yielded the lowest RBDZ in all gaits, aligning with existing research identifying the breast-stabilizing effects of combination bras during high-movement activities [23,28]. While this was generally consistent with previous findings in equine simulator gaits [24], an unexpected finding was that RBDZ was higher in the walk gait than in canter. Although canter involves larger horse–rider movement, walk may require more nuanced postural control and fine motor adjustments from the rider, potentially contributing to increased movement of the breast relative to the trunk. Studies of horse–rider interaction support this interpretation, with walk reported as a technically challenging gait requiring careful control and often demonstrating lower rider-horse coordination than canter [47–49]. These findings highlight the need for further investigation of breast biomechanics during walk, a gait that remains relatively under-researched despite its importance as the foundation of equine warm-up and training routines [50].

Breast support condition had variable effects across displacement directions, with vertical breast displacement most consistently reduced and mediolateral breast displacement showing limited change during equestrian gaits. This directional specificity is aligned with previous findings that different physical activities elicit distinct breast motion profiles [51]. Collectively, these data suggest that bras designed primarily for running may not adequately address the multidirectional loading patterns encountered during horse riding.

The moderate positive correlations identified between EIBP and RBD across all planes reinforce the established link between excessive breast motion and increased pain during equestrian activities [24]. Reducing relative breast displacement remains an important strategy to improve rider comfort and sustain equestrian participation. These findings will inform future educational strategies targeted at female equestrians, not only to bridge the information gap previously identified [52], but also to reinforce the importance of suitable bra selection to meet the breast support demands of the multidirectional loading characteristic of equestrian activities.

4.3. Rider Position

One of the novel contributions of this study is that breast support affects rider symmetry. In trot, a symmetrical gait, the ESB condition produced the greatest elbow and knee symmetry, i.e., the smallest differences between left and right movement patterns. An asymmetrical rider position has been linked to reduced performance, laterality, pain, and increased injury risk [13,14,53,54]. Reduced rider asymmetry may contribute to better tactile cue application, improving communication with the horse, enhancing rider stability, honing rider skill, and subsequently impacting the experience of the ridden horse.

Consistent with previous findings [24], higher breast support brought the rider's torso closer to the vertical in trot. More upright torso positions are associated with greater equestrian skill levels [15], suggesting that inadequate breast support may compromise rider biomechanics by mimicking those of lower skill levels or reduce the efficacy of tactile cue application to the horse. These findings highlight the consequences of breast support beyond rider comfort, suggesting that avoiding excessive breast movement enhances rider performance, potentially improving welfare of the ridden horse.

4.4. Bra Comfort, Usability, and Design Considerations

Post-data collection survey findings highlighted that participants' bra preferences were not solely determined by breast support level, but also by bra comfort, appearance, strap design, and ease of use. These factors are heavily influenced by the demands of equestrian practice, including prolonged wear, yard work, and the aesthetics of equestrian competition attire [25,37,55,56].

While CSB was perceived to provide the greatest breast support and was the preferred option for both riding and running, some participants expressed concerns regarding fastening complexity and long-term comfort. Conversely, ESB was often described as comfortable and visually appropriate

for equestrian wear but received criticism for shoulder-strap slippage and insufficient support during sitting trot, the gait consistently identified as generating high breast movement and pain [24,25,33].

These divergent preferences highlight that female equestrians require bras designed not only for breast support but also for ease of movement, secure yet uncomplicated strap systems, discreet aesthetics, and prolonged wearability consistent with occupational demands [57]. This reinforces the need for equestrian-specific bra design rather than reliance on running-focused sports bras, with further longitudinal field-based studies warranted.

4.5. Limitations and Future Directions

The relatively limited sample size, and particularly the lower representation of large-breasted riders, may have limited the ability to detect size-related differences in EIBP and RBD. Additionally, while the equine simulator may not fully replicate the dynamics of a live horse [58], rider position is comparable in trot [59]; it does provide a controlled and private environment necessary for collecting sensitive data.

Although participants declared they were "regular" runners and capable of running at approximately 2.5 m/s on a treadmill, fatigue may have impacted results. However, running trials were limited to 60 seconds in each breast support condition, so fatigue impacts were likely to be limited.

The findings from the current study suggest there is a need for an equestrian-specific bra design to not only meet the breast support requirements of the multidirectional loading observed, but also the comfort and aesthetic needs of this population to promote sports bra wear. It should be noted, however, that the post-data collection survey did not ask about the motivations for bra selection or non-selection, and future studies should include factors influencing bra choices in greater detail.

Educational and awareness strategies are advisable within the wider equestrian population, including coaches, to increase knowledge and awareness of suitable breast support choices and adoption of sports bra wear while horse riding. Future research should incorporate field-based studies using live horses and larger, more representative samples. Longitudinal assessment of bra performance under real-world wear conditions, such as multiple equestrian training sessions, competitions, and combined riding/yard-work days, would provide further insight into the occupational suitability of bras for equestrian activities.

5. Conclusion

Breast support meaningfully influenced breast motion, pain, and rider biomechanics within this sample of female equestrians. Higher-support bras improved comfort, reduced RBD, and enhanced rider symmetry and torso alignment, demonstrating functional implications for rider performance and potentially critical aspects of horse–rider communication that may affect equine welfare. These results highlight the need for equestrian-specific bra design and practical guidance tailored to the unique movement and aesthetic demands of this sporting population.

Supplementary Materials

Supplementary File 1 contains the Post-Data Collection Questionnaire. **Supplementary File 2** contains detailed post-hoc analysis results for exercise-induced breast pain and relative breast displacement, presented in Tables S1–S3.

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Authors' Contributions

L.C.: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Project administration. N.S.: Technical provision, Writing – review & editing. V.L., E.D., J.L.D., C.M. & K.S.: Conceptualization, Methodology, Data curation, Writing – review & editing. J.B.: Conceptualization, Methodology, Writing – review & editing.

Data Availability

The data supporting the findings of this study are available upon reasonable request from the corresponding author.

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No funding was received for this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Ethical Approval

This study received ethical approval from the Hartpury University Ethics Committee (ETHICS2023-74). The study complied with the guidelines of the Declaration of Helsinki.

Consent to Participate

Participants provided informed consent prior to data collection and declared that they regularly took part in the level of physical activity detailed in the participant information sheet.

Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this work, the authors used Microsoft Copilot to improve readability. Following the use of this tool, the authors reviewed and edited the content as needed and take full responsibility for the final version of the publication.

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