

**Breast biomechanics, exercise induced breast pain (mastalgia), breast support condition and its impact on riding position in female equestrians**

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*Published in:*  
Comparative Exercise Physiology

*Publication date:*  
2022

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[10.3920/CEP210005](https://doi.org/10.3920/CEP210005)

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*Citation for published version (APA):*  
Cameron, L., Burbage, J., Lewis, V., Dumbell, L., Billingsley, E., Young, K., King-Urbin, C., & Goater, F. (2022). Breast biomechanics, exercise induced breast pain (mastalgia), breast support condition and its impact on riding position in female equestrians. *Comparative Exercise Physiology*, 18(1), 9-19.  
<https://doi.org/10.3920/CEP210005>

1 **Breast biomechanics, exercise induced breast pain (mastalgia), breast support condition**  
2 **and its impact on riding position in female equestrians.**

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11 **Running header – Female equestrian breast biomechanics**

12 **Abstract**

13 Breast biomechanics, exercise-induced breast pain (EIBP) and performance effects in female  
14 athletes are established. Wearing sports bras during exercise reduces breast movement and  
15 EIBP. Despite the prevalence of female equestrians, little investigation of breast movement  
16 during horse riding exists, yet excessive breast movement, embarrassment and EIBP are  
17 reported. Breast movement relative to the torso is linked to EIBP, associated with magnitude  
18 and direction of forces generated. Equestrians may experience novel breast and upper-body  
19 movement patterns in response to large vertical excursions of the horse. This study aimed to  
20 establish relative vertical breast displacement (RVBD), EIBP and positional changes in three  
21 support conditions; “no support”, “low support” and “high support”. Thirty-eight female  
22 equestrians rode a Racewood™ Equine Simulator in each breast support condition in medium  
23 walk, medium trot (sitting) and medium canter. Trials were filmed and analysed using  
24 Quintic® Biomechanics V29. Significant reductions in RVBD ( $P < 0.001$ ) and EIBP ( $P <$   
25  $0.001$ ) were identified with increased breast support in all gaits. In medium trot (sitting) a  
26 significant reduction in range of movement (ROM) of shoulder-elbow-wrist ( $P < 0.001$ ) was  
27 seen from low to high support. ROM of torso-vertical angles were reduced from no support to  
28 low support ( $P < 0.001$ ) and further by high support ( $P < 0.001$ ). This reduction in ROM was  
29 significantly greater in large breasted riders (Cup size DD – FF) ( $n = 21$ ) ( $P < 0.001$ ) compared  
30 to small breasted (Cup size AA – D) ( $n = 17$ ). These results suggest that appropriate breast  
31 support positively impacts EIBP and riding position in female riders possibly enhancing  
32 performance. As RVBD and reported EIBP were not wholly comparative with results in female

33 runners, further research is warranted to establish breast movement in equestrianism in three  
34 dimensions.

35 **Keywords;** *Equestrian performance, pain perception, rider skill*

36

## 37 **Introduction**

38 Sport England Active Lives Survey (Sport England, 2020) identified men are more likely to be  
39 active than women with 65% of men and 61% of women classing themselves as active on a  
40 weekly basis. Of these sports, equestrianism accounted for 3.6% of total female sporting  
41 participation with 73.5% of horse riders being female. The National Equestrian Survey 2019  
42 (BETA, 2019) reported 1.8 million regular horse riders within UK equestrianism. Exercise-  
43 induced breast pain (EIBP) has previously been identified as a barrier to sport participation for  
44 females and is reported to impact quality of life (Burbage & Cameron, 2018; Burnett *et al.*,  
45 2015; Scurr *et al.*, 2016; Scurr *et al.*, 2014; Mason *et al.*, 1999). Burnett *et al.* (2015) reported  
46 breast issues as the fourth largest barrier to physical activity in females above previously  
47 identified factors such as financial cost and lack of sporting facilities.

48 Research has previously established that excessive breast movement, specifically that induced  
49 by exercise, can cause pain or discomfort (Brown & Scurr, 2016; White *et al.*, 2009; Mason *et al.*  
50 *et al.*, 1999; Scurr *et al.*, 2016, 2014). Analysis of breast movement has determined differing  
51 ground reaction forces, breast displacement, velocity and acceleration impacted by type and  
52 level of activity with greater activity levels resulting in more breast movement (Brown *et al.*,  
53 2014; White *et al.*, 2009; Mason *et al.*, 1999). Burbage and Cameron (2017) investigated the  
54 prevalence and impact of breast pain within a horse riding population (n = 1324), finding that  
55 nearly 30% of respondents reported breast pain and over half of these respondents stated that  
56 the breast pain was discomforting. A well-fitting, appropriate sports bra has been demonstrated  
57 to reduce breast motion and related pain (Scurr *et al.*, 2010; White *et al.*, 2009). The majority  
58 of current knowledge of EIBP is based upon research conducted in female running populations  
59 (Haake & Scurr, 2011; Scurr *et al.*, 2011; Scurr *et al.*, 2009; White *et al.*, 2009; Mason *et al.*,  
60 1999). Risius *et al.* (2016) examined breast kinematics during different exercise modalities  
61 finding that breast movement in the vertical, mediolateral and anterioposterior direction differs  
62 according to exercise mode, suggesting that horse riding may elicit unique breast movement in  
63 the female rider.

64 The female breast in adults is a modified subcutaneous gland consisting of soft tissue, within  
65 the superficial fascia of the anterior chest wall (Mason *et al.*, 1999; McGhee & Steele, 2020).  
66 The breast is mostly composed of interlobular adipose tissue and small amounts of epithelial  
67 glandular tissue. Loose areolar tissue beneath the layer of superficial fascia, allows free  
68 movement of the breast in relation to the chest wall (Mason *et al.*, 1999). Fibrous connective  
69 tissue surrounds the glandular tissue, extending from the pectoral muscle to the skin to form  
70 Cooper's ligaments. These are thought to provide some support to the breast (Page & Steele,  
71 1999), however the skin is thought to be the primary supporting structure for the breast and can  
72 be subject to peak stretching of up to 93% in bare breasted running (Norris *et al.*, 2020).  
73 Research has shown that excessive movement of the breasts during exercise can result in large  
74 forces being exerted on these delicate support structures (Norris *et al.*, 2020) resulting in pain  
75 and possibly subsequent damage. Therefore, wearing a sports bra that provides adequate  
76 support is advised for the exercising female (McGhee *et al.*, 2013).

77 Despite the gender bias towards female participants in equestrianism (Sport England, 2020),  
78 there is little research detailing breast biomechanics in female equestrians where rider body  
79 movements are dictated by large vertical excursions of the horse (Terada *et al.*, 2006). Each  
80 equine gait has specific footfalls which impacts the vertical motion, magnitude and direction  
81 of forces the rider must absorb (Douglas *et al.*, 2012). Burbage *et al.* (2016) conducted a  
82 preliminary study using a small sample of female horse riders, finding vertical breast  
83 displacement and breast pain were greatest at trot (sitting) and that both were significantly  
84 reduced by appropriate breast support on a horse simulator, however a larger study was  
85 suggested to explore the health effects of breast motion on female equestrians.

86 The prevalence of breast pain in the female horse riding population, reported as 40% (Burbage  
87 & Cameron, 2017), was slightly higher than that reported by marathon runners (Brown *et al.*,  
88 2014). However, equestrian sports are, by nature, novel within sports science research  
89 (Williams, 2017) and findings from breast research in other sports may not be applicable. The  
90 partnership between a human and non-human athlete performing on a sporting stage is one  
91 fraught with the possibility of miscommunication and as a result, danger (Nylund *et al.*, 2019).  
92 The equine member of this partnership has been the subject of much research to enhance  
93 performance and assure welfare (e.g. Pierard *et al.*, 2019; Dyson, 2017; McGreevy & McLean,  
94 2009) to the exclusion, until very recently, of the human partner. Recent developments in  
95 equestrian sport have seen winning margins at Olympic and World Championship level reduce  
96 to very small amounts, often less than one penalty point or percentage, dependent on discipline

97 triggering more interest in the marginal gains (Williams, 2013) that may be achievable by  
98 minimal adjustments to the performance, skill, balance or emotional state of the rider  
99 (Engenvall *et al.*, 2020; Martin *et al.*, 2016; Strunk *et al.*, 2018; Wolframm & Micklewright,  
100 2010). This increased interest in rider performance has led to an upsurge in research  
101 considering the impact of a range of factors on the overall ability of the rider to perform at their  
102 optimal level (Clayton & Hobbs, 2017).

103 It has been recognised by equestrian researchers that an asymmetrical posture in either horse  
104 or rider affects symmetry of the other (MacKenchnie Guire *et al.*, 2020), and has been  
105 associated with problems such as back pain in horse and rider (Gunst *et al.*, 2019), uneven  
106 equine muscular development (Nevison & Timmis, 2013), and a decrease in the clarity of  
107 communication between horse and rider (Eckardt & Witte, 2017). The rider may not even be  
108 aware of their own asymmetries (Guire *et al.*, 2017). As the rider communicates their wishes  
109 to the horse via tactile cues and the timely removal of these cues constitute negative  
110 reinforcement within the training of the horse (Warren-Smith & McGreevy, 2007), any factor  
111 that may negatively impact the position or movement of the rider on the horse will impact  
112 training efficacy, competition performance and subsequently equine welfare (Williams &  
113 Tabor, 2017). Several researchers have reported the influence asymmetry, stiffness and pain in  
114 the rider may have on equine biomechanics and welfare, therefore breast pain in the rider, if  
115 impacting rider position, may negatively affect the horse inducing lameness, reducing  
116 trainability, decreasing performance and potentially compromising welfare (Greve & Dyson,  
117 2014; Randle *et al.*, 2010).

118 Postural characteristics of dressage riders have been studied using three dimensional (3D)  
119 analysis (Alexander *et al.*, 2015), trunk lateral flexion and asymmetry were shown to be  
120 prevalent. Risius *et al.* (2014) reported different exercise modes changed both magnitude and  
121 distribution of multiplanar breast kinematics and Burbage and Cameron (2016) suggest that the  
122 motion experienced by horse riders may be unique suggesting that breast motion may impact  
123 rider dynamic postural characteristics. The object of rider positional analysis is to ensure that  
124 the rider stays in balance with the horse as asymmetry, stiffness or pain have been demonstrated  
125 to produce a negative influence on the equestrian partnership (Greve & Dyson, 2014;  
126 Hockenhall & Creighton, 2012; Randle *et al.*, 2010). If breast support condition in the rider is  
127 confirmed to significantly impact relative breast movement, associated breast pain and  
128 subsequent rider position, this in turn could imply possible equestrian performance and equine  
129 welfare implications of inadequate breast support in female horse riders. It is hypothesised that

130 breast support condition will significantly impact relative vertical breast displacement  
131 (RVBD), exercise induced breast pain (EIBP) and associated postural changes in a sample of  
132 female horse riders on an equine simulator.

133

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134

## 135 **Materials and Methods**

136 Following institutional ethical approval, 38 female recreational horse riders between the ages  
137 of 18 and 39 years old (to reduce the impact of age related breast changes), with bra sizes  
138 ranging from a UK 32 to 36 band size and between AA and FF cup size (Table 1) were recruited  
139 from the local equestrian community, college students and staff via word of mouth, posters and  
140 social media. Due to the changes in the breast caused by pregnancy, breast feeding and surgery  
141 (McCool *et al.*, 1998; Page & Steele, 1999) participants were excluded if they were currently  
142 pregnant, had breast-fed within the last year or had previously undergone breast surgery. Bra  
143 fitting was applied to all participants according to professional best-fit criteria (White & Scurr,  
144 2012) and allocated to a “large-breasted” group (Cup size DD – FF) (n = 21) or a “small-  
145 breasted” group (Cup size AA – D) (n = 17), as determined in previous research (Burbage &  
146 Cameron, 2017). Each participant completed a 120 second habituation on the Racewood™  
147 Equine Simulator, comprised of 30 seconds at medium walk, 30 seconds at medium trot  
148 (sitting), 30 seconds at medium canter right and 30 seconds at medium canter left. Participants  
149 completed three trials with high, low, or no breast support. The order of breast support  
150 conditions were randomly allocated (other than no support which involved riding bare  
151 breasted), either an everyday bra considered “low support” in previous studies (White *et al.*,  
152 2009) (plain, non-padded, underwired T-shirt bra, made from 78% polyamide and 22%  
153 elastane; Marks & Spencer™) or riding bra considered “high support” (padded, underwired  
154 riding bra, made from 75% polyamide and 25% elastane, Berlei™) chosen as the only bra  
155 specifically marketed for horse riding in the UK. Reflective markers (B&L Engineering  
156 Reflective Markers 9.5mm sphere, base 17mm hard plastic) were positioned on each nipple,  
157 over the bra when worn, and the suprasternal notch (Mason *et al.*, 1999; Scurr *et al.*, 2011;  
158 Scurr *et al.*, 2009) (Figure 1). In addition, markers were placed on the acromium, lateral  
159 epicondyle of the distal humerus, radius styloid process, greater trochanter, lateral epicondyle  
160 of the distal femur and lateral malleolus on the left side of all participants (Kang *et al.*, 2010).  
161 Each participant completed a total of nine trials on the Riding Simulator (Racewood™, UK) at

162 either Quob Stables, Durley, Hampshire U.K. or Hartpury University, Gloucester, U.K. For  
163 every participant, each trial consisted of 60 seconds in medium walk, medium trot (sitting) and  
164 medium canter (right) with the final 30 seconds of each gait being video recorded (Apple Inc.,  
165 USA) apart from the “no support” condition of 30 seconds in each gait, due to the associated  
166 discomfort expected and in recognition of the exposed nature of this condition, all of which  
167 was recorded. Cameras (iPad Air, Apple Inc., USA) were placed directly in front and on the  
168 left side of the rider and trials were completed in three breast support conditions, “low support”  
169 and “high support” randomly assigned and “no support”, where participants rode bare breasted,  
170 always completed last to enable participants to feel more comfortable with the data collection  
171 process before being asked to ride bare breasted. Trials took place in a secure and screened  
172 room to ensure privacy with a maximum of three female researchers present. Each bra was  
173 checked for fit on all participants before the trial commenced. Directly after every breast  
174 support condition in each gait participants rated their exercise induced breast pain on a 100mm  
175 Visual Analogue Score (VAS) from 0mm (no pain) to 100mm (extreme pain).

176 **Table 1 here**

177 **Figure 1 here**

178 Anatomical markers were digitised within Quintic® Biomechanics V29 software and  
179 smoothed using a 2nd order Butterworth Filter (automated optimal filter values) for each breast  
180 support condition and simulator gait combination, and used to determine relative vertical breast  
181 displacement (RVBD) (mm) and rider position (shoulder – elbow - wrist, shoulder – hip – knee,  
182 hip – knee – ankle, torso – vertical) (degrees) over five full stride cycles within each gait and  
183 each condition. The highest recorded point of the suprasternal notch determined the beginning  
184 of each cycle in canter and two recorded consecutive highest points of the suprasternal notch  
185 determining the beginning of each cycle in walk and trot due to the double bounce effect  
186 observed in these gaits. To determine relative vertical breast displacement (RVBD), the range  
187 of movement (ROM) of the suprasternal notch (SN), left nipple (LN) and right nipple (RN)  
188 were calculated.

189 Exercise Induced Breast Pain (mm) was obtained by measuring participant recorded points on  
190 the VAS giving a value for each participant in each gait and breast support condition. The  
191 minimum and maximum angles for each joint for participants were recorded for the same five  
192 gait cycles. Variation of the rider’s torso from the vertical was also calculated resulting in four  
193 measures of rider position: shoulder-elbow-wrist range of movement (SEWROM), shoulder-

194 hip-knee range of movement (SHKROM), hip-knee-ankle range of movement (HKAROM)  
195 and torso deviation from vertical (VERTROM).

196 Data were checked for normality using Anderson-Darling tests and analysed using a repeated  
197 measures analysis of variance (ANOVA) ( $P < 0.05$ ). Post-hoc testing of differences were  
198 completed using Paired T Tests or Mann Whitney U Tests where appropriate, with a Bonferroni  
199 Correction of ( $p < 0.0017$ ) applied.

200

201

202

## 203 **Results**

204 Relative vertical breast displacement (RVBD) (mm) was significantly impacted by breast  
205 support conditions ( $F = 136.9$ ,  $df = 2$ ,  $P < 0.001$ ), gait ( $F = 289.57$ ,  $df = 2$ ,  $P < 0.001$ ) and breast  
206 size group ( $F = 34.49$ ,  $df = 1$ ,  $P < 0.001$ ) (Figure 2). Regardless of breast size category, mean  
207 ( $\pm$  SD) unsupported vertical breast displacement was highest during medium trot ( $44.15\text{mm} \pm$   
208  $9.4$ ), reducing in the low support condition ( $41.59\text{mm} \pm 8.36$ ) and further reductions observed  
209 in the high support condition ( $20.8\text{mm} \pm 7.73$ ). A significant difference in EIBP was identified  
210 by gait ( $F = 44.32$ ,  $df = 2$ ,  $P < 0.001$ ), breast support condition ( $F = 34.69$ ,  $df = 2$ ,  $P < 0.001$ )  
211 and breast size group ( $F = 15.44$ ,  $df = 1$ ,  $P < 0.001$ ) with the highest mean ( $\pm$  SD) VAS for the  
212 whole group in medium trot (sitting) in the unsupported condition ( $33.13\text{mm} \pm 21.45$ ) (Figure  
213 4). No significant differences between support conditions were seen in SHKROM or  
214 HKAROM in any gait. However, significant differences were seen in SEWROM ( $F = 19.19$ ,  
215  $df = 2$ ,  $P < 0.001$ ) and VERTROM ( $F = 63.42$ ,  $df = 2$ ,  $P < 0.001$ ) dependent on breast support  
216 condition. In medium trot (sitting) mean VERTROM ( $\pm$  SD) was significantly higher ( $F =$   
217  $43.89$ ,  $df = 1$ ,  $P < 0.001$ ) in the large-breasted group ( $7.99$  degrees  $\pm 3.11$ ) than the small-  
218 breasted group ( $5.5$  degrees  $\pm 2.98$ ).

## 219 **Table 2 here**

220 Post-hoc analysis ( $P < 0.0017$ ) revealed in the low support condition, RVBD was not  
221 significantly reduced from the no support condition in medium walk or medium trot (sitting)  
222 but was significantly reduced in medium canter ( $T = -7.35$ ,  $P < 0.001$ ) (Figure 2). The high  
223 support condition significantly reduced RVBD compared to the low support condition in



224 medium walk ( $T = 8.89, P < 0.001$ ), medium trot (sitting) ( $T = 15.88, P < 0.001$ ) and medium  
225 canter ( $T = 12.27, P < 0.001$ ) with the greatest reduction observed between low support ( $M =$   
226  $41.59\text{mm} \pm 8.36$ ) to high support ( $M = 20.08\text{mm} \pm 7.73$ ) in medium trot (sitting). No influence  
227 of breast size was observed on percentage reduction of RVBD.

228

229 **Figure 2 here**

230 **Figure 3 here**

231

232 Reporting of EIPB was significantly reduced in medium trot (sitting) ( $T = 5.54, P < 0.001$ ) and  
233 medium canter ( $T = 5.65, P < 0.001$ ) in the low support condition compared to the no support  
234 condition across all breast sizes. Exercise Induced Breast Pain was significantly reduced again  
235 from low support to high support ( $T = 5.47, P < 0.001$ ) in medium walk, medium trot (sitting)  
236 ( $T = 7.71, P < 0.001$ ) and medium canter ( $T = 6.47, P < 0.001$ ) (Figure 4). Large-breasted riders  
237 reported a greater reduction in EIBP in the high support condition versus low support in  
238 medium trot (sitting) than the small-breasted group ( $W = 299, P = 0.001$ ) although the small  
239 breasted group did report some reduction in EIBP with increased support, however no  
240 significant impact of breast size on reported EIBP was observed in other gaits (Figure 5).

241

242 **Figure 4 here**

243 **Figure 5 here**

244

245 Rider position was unaffected by breast support condition in medium walk and medium canter.  
246 In medium trot (sitting) only, SEWROM significantly reduced ( $T = 13.3, P < 0.001$ ) when  
247 participants wore low breast support, compared to high breast support and this was unaffected  
248 by breast size. Torso deviation from vertical (VERTROM) was significantly reduced from the  
249 unsupported condition to the low support condition ( $T = 9.12, P < 0.001$ ) and further reduced  
250 when compared to the high support condition ( $T = 10.23, P < 0.001$ ) (Figure 6). Large-breasted  
251 riders' VERTROM was reduced significantly more ( $W = 304, P < 0.001$ ) in the high support  
252 condition (median =  $6.2 \text{ degrees} \pm 2.4$ ) than the small-breasted group (median =  $2.1 \text{ degrees} \pm$   
253  $2.7$ ) compared to low support (Figure 7).

254 **Table 3 here**

255 **Figure 6 here**

256 **Figure 7 here**

257

## 258 **Discussion**

259 To our knowledge, this is the first research to investigate the effect of breast support condition  
260 on breast kinematics, EIBP and body position in female equestrians. The movements that a  
261 rider must absorb when on a horse in a variety of gaits may well generate movement patterns  
262 that are unique to equestrianism (Burbage & Cameron, 2017). Understanding these unique  
263 movements may prove beneficial as the rider communicates with and controls the horse  
264 through the application of tactile cues (Warren-Smith & McGreevy, 2007) and control of the  
265 body may well impact the rider's ability to apply these cues with clarity, enabling the horse to  
266 readily distinguish between different cues and provide the desired response (McLean &  
267 Christensen, 2017). Significant differences by breast support condition in RVBD (Figure 2)  
268 and EIBP (Figure 4) are similar to existing research in populations of female runners (White *et*  
269 *al.*, 2009), however displacement and reported pain, even in the medium trot (sitting) gait,  
270 previously reported to be the most painful equine gait in survey data (Burbage & Cameron,  
271 2018) were smaller than previously reported in running populations. This suggests that further  
272 investigation is warranted to compare these participants in different activities and in three  
273 dimensions as the movement of the breast in horse riding may be more complex than in running  
274 for example, as dorso-ventral and medio-lateral movements may be associated with the  
275 movements generated in response to the horse's gait. The lower level of reported EIBP in this  
276 sample of riders could also be due to the short duration of each trial (60 seconds) compared to  
277 recollections of EIBP (Burbage & Cameron, 2018) which would likely have been induced by  
278 a much longer duration of horse riding, typically around one hour, or the cumulative effect of  
279 repeated riding bouts either within one day or over multiple days. Menstrual stage was also not  
280 recorded for participants within this study which can, in itself, induce pain or tenderness within  
281 the breast (Scurr *et al.*, 2014) and should be considered in future female equestrian breast  
282 research.

283

284 In female runners, breast support condition has not been shown to impact upper body extremity  
285 movement (White *et al.*, 2015) but Milligan *et al.* (2015) did find improved running form in  
286 5km runners associated with appropriate breast support. In this study of female horse riders,  
287 shoulder-elbow-wrist range of movement (SEWROM) and torso range of movement around  
288 the vertical (VERTROM) were significantly impacted by breast support condition (Figure 6),  
289 although only in the medium trot (sitting) gait, with these changes being significantly greater  
290 in large-breasted riders. This may well be due to medium trot eliciting the largest vertical  
291 excursion of the horse's body with the largest relative vertical breast displacement in the no  
292 support condition observed in this gait. Although no significant differences in lower body  
293 position were observed in this study, the position of the rider's torso around the vertical has  
294 been previously indicated to be related to rider skill (Kang *et al.*, 2010) with those riders at a  
295 higher level of skill retaining a torso position closer to the vertical. Riders within the current  
296 study were of generally similar horse riding skill level, however future research should consider  
297 the impact of breast support on riders of different skill levels and disciplines to inform  
298 appropriate advice accordingly. The change in rider position observed in this study does  
299 suggest that suitable breast support for horse riding, especially in large-breasted riders, may  
300 actually improve female equestrian skill, potentially improving communication with the horse  
301 and positively impacting subsequent performance. As the reduction in movement of the rider's  
302 torso around the vertical was most evident within the large-breasted group of riders, further  
303 investigation is warranted in larger breasted riders. Milligan *et al.* (2015) highlighted a lack of  
304 consideration of breast support on human movement investigating the influence of breast  
305 support on torso, pelvis and arm kinematics during a 5 km treadmill run and found that, when  
306 the breast was well supported, pelvis and upper arm kinematics more closely aligned with  
307 economical running form, suggesting that appropriate breast support may enhance performance  
308 in female middle-distance runners. In view of this, further research into the effect of breast  
309 movement and different breast support conditions on rider kinematics may further aid both  
310 horse/rider communication and equine welfare (Randle *et al.*, 2010) and reduce breast-related  
311 barriers to equestrian participation (Burbage & Cameron, 2018). Large-breasted riders may  
312 therefore be advised to be especially mindful of appropriate breast support when horse riding  
313 to possibly improve riding performance.

314 The horse rider also communicates cues to the horse with pressure from their hands via rein  
315 contact to the horse's mouth, with the negative reinforcement to reward a desired behaviour  
316 being the release of this pressure (McLean & Christensen, 2017). Rein contact and tension is

317 an area of research interest (Williams & Barnett, 2013) with much attention being paid to the  
318 importance of the rider's ability to release this negative reinforcement immediately on the  
319 performance of the desired behaviour from the horse. Hausberger *et al.* (2009) states that this  
320 inability of the rider to release negative reinforcement at the appropriate time and the  
321 subsequent "work environment" for the horse is often the basis of multiple conflict behaviours  
322 expressed in competition and leisure horses. When measuring wrist stabilisation in experienced  
323 horse riders, Terada *et al.* (2006) found that there was variability in wrist position throughout  
324 the equine stride cycle, but that these experienced riders were able to stabilise the wrist,  
325 suggesting that this is an important characteristic of competent riding. In the present study,  
326 increased breast support significantly reduced the range of movement observed in the riders'  
327 shoulder-elbow-wrist angle, although this was not related to breast size, possibly creating a  
328 more controlled hand position in trot. This raises the possibility that inadequate breast support  
329 when horse riding may be negatively impacting the rider's ability to effectively release the rein  
330 contact with accurate timing, however rein tension in different breast support conditions was  
331 not measured in this study and warrants further investigation.

332 Reported EIBP was significantly reduced by increased breast support, agreeing with previous  
333 research in female runners. Burbage and Cameron (2017) reported that only 27% of the 1324  
334 riders surveyed exclusively rode in a sports bra although 25% of respondents reported at least  
335 one breast related barrier (Burbage & Cameron, 2018) to their participation in horse riding and  
336 that reported pain increased linearly with breast size. Appropriate breast support when horse  
337 riding may be particularly important for large-breasted riders as the reduction in EIBP was  
338 significantly higher in large-breasted riders in medium trot (sitting) from no support to high  
339 support. These findings indicate that further research and dissemination of results is required  
340 within the horse riding population to mediate the impact of breast issues as a barrier to  
341 participation, potentially increasing female equestrian participation in future.

342 Changes observed in rider upper body position in this study may be due to the impact of breast  
343 support condition on rider pain or muscular activity. Increased breast support significantly  
344 reduced rider EIBP, particularly in the medium trot (sitting) gait where the only significant  
345 differences in rider upper body parameters were observed, however it should be noted that the  
346 variation in EIBP was large and impacted by the individual which may account for some of the  
347 variation in results. Several studies have highlighted the incidence of competitive riders  
348 performing when in pain (Lewis & Baldwin, 2018; Lewis & Kennerley, 2017) and reporting  
349 that this pain has negatively impacted their equestrian performance. These differences in upper

350 body positioning in trot, although statistically significant, may not be biologically significant  
351 and equine parameters in response to these changes should be monitored. Future studies should  
352 also investigate the impact of breast support, relative vertical breast displacement, breast size  
353 and EIBP on upper body muscular activity as this may be the cause of the positional changes  
354 seen and would further impact the rider's ability to communicate clearly through the rein aids  
355 (Terada *et al.*, 2006).

356 It should be noted that the sample size within this study was relatively small with a  
357 comparatively large range of breast sizes reported which may have adversely affected results.  
358 Riders were only observed on an equine simulator, and although Dumbell *et al.* (2015) reported  
359 no significant differences in rider position between riding an equine simulator and a real horse,  
360 the riders within the present study were not required to control the simulator or apply any  
361 cues/aids within the trials which may have an impact on rider position, balance and movement.  
362 The riders were of reasonably similar horse riding ability, however it should be noted that there  
363 was no measurement of this ability and the parameters were wide, possibly having an impact  
364 on subsequent results. Only three specific gaits were used, medium walk, medium trot (sitting)  
365 and medium canter and these are not the full range of equine movements that a rider would  
366 have to absorb in various competitive disciplines such a show jumping or advanced dressage  
367 (Federation Equestre Internationale, 2020). Rider position and relative vertical breast  
368 displacement were also only monitored in two dimensions (2D), and although novel within  
369 equestrianism, these methods have been superseded in the wider sports science literature by  
370 measurements in three dimensions (3D) (Mills *et al.*, 2016). Future studies, utilising an equine  
371 simulator capable of replicating a wider range of equestrian movements, 3D motion capture  
372 technology and a wider range of female equestrian ability are indicated.

### 373 **Conclusions**

374 The significant decreases found in RVBD, VERTROM, SEWROM and EIBP due to increased  
375 breast support condition in female equestrians may influence equitation skill level and warrants  
376 further investigation to promote increased female equestrian participation and potentially  
377 improve rider skill and subsequent equine welfare during horse riding and training activities.

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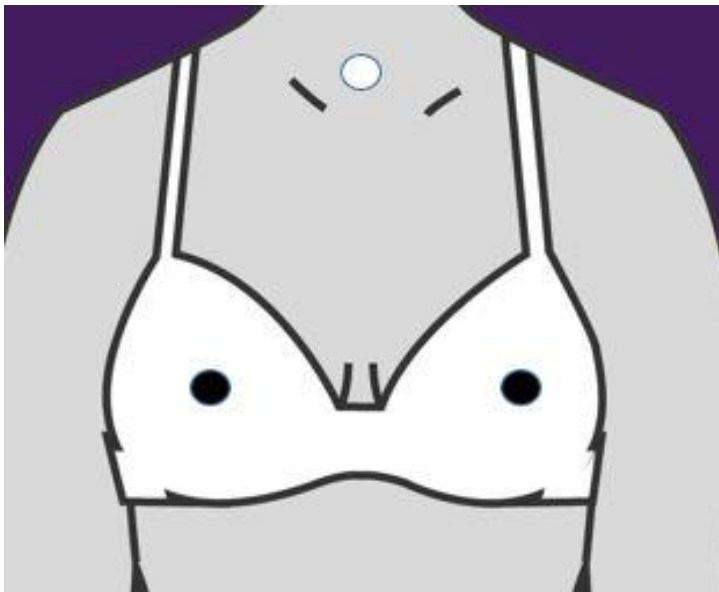
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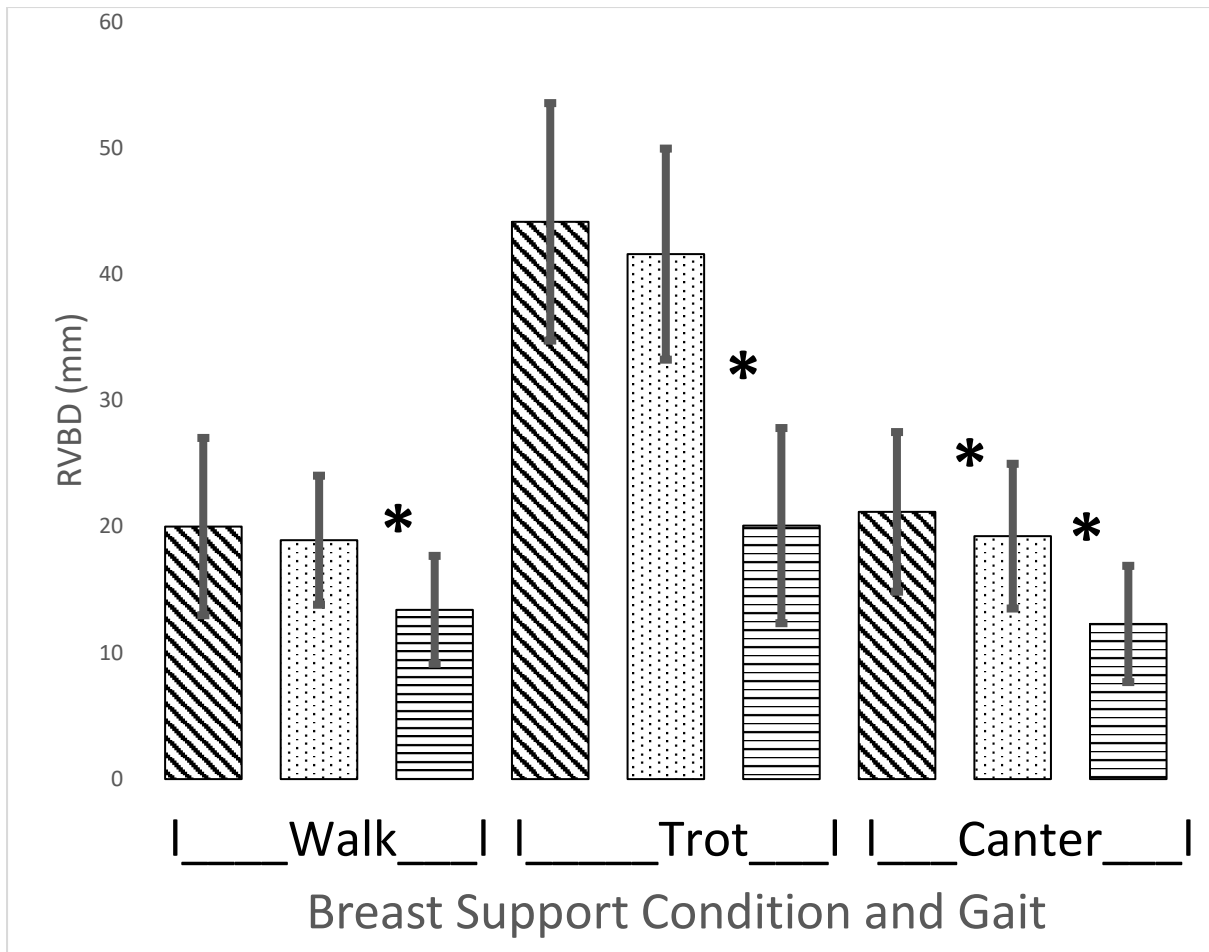
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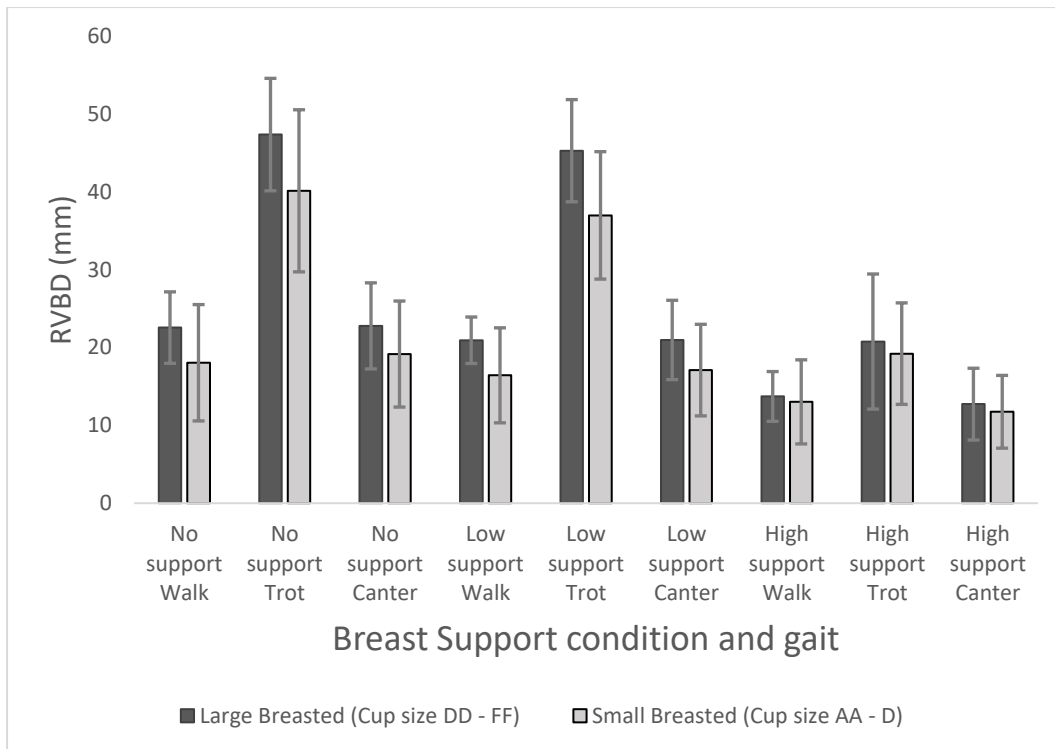
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518 Figure 1 Placement of reflective markers on each nipple and suprasternal notch



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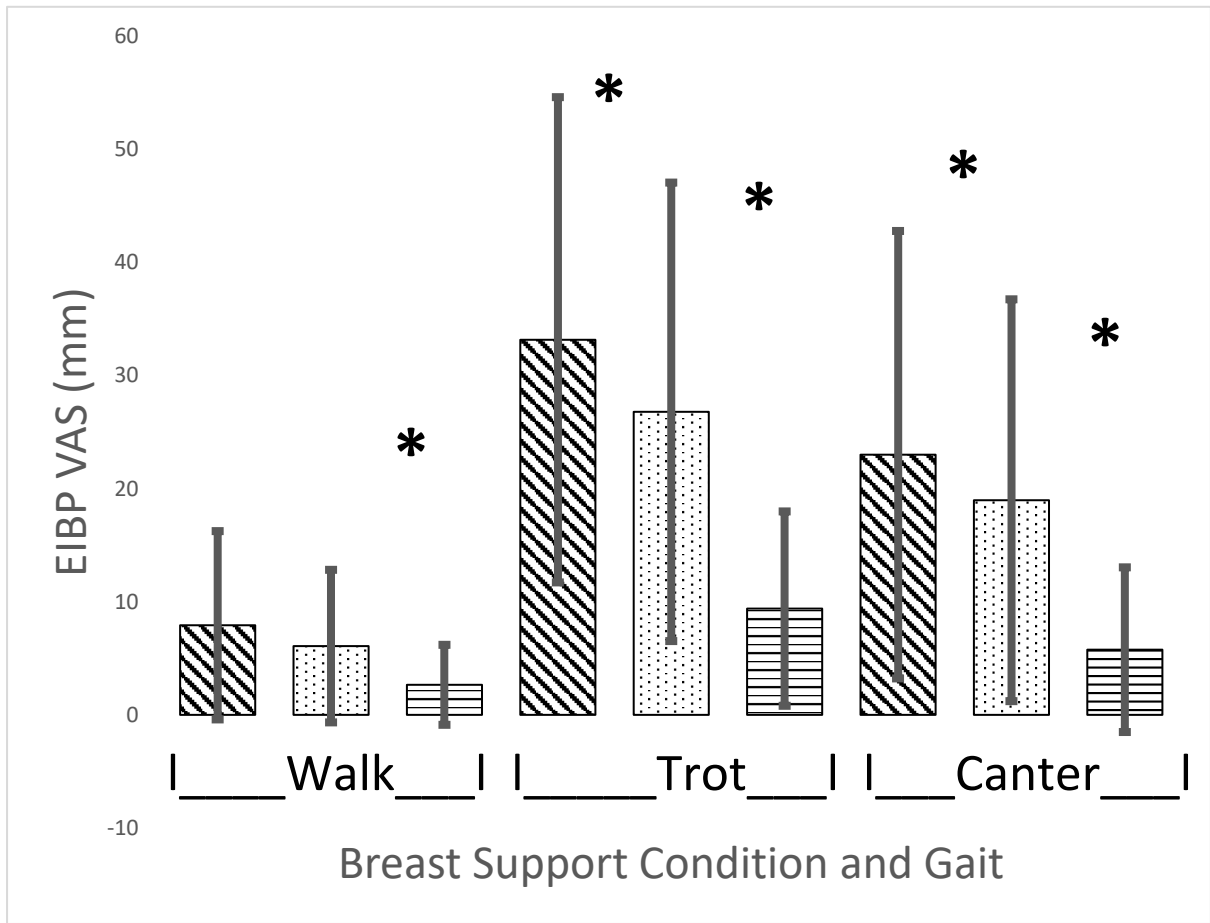
520 Figure 2 Bar chart to show impact of breast support condition (all breast sizes) on Relative  
 521 Vertical Breast Displacement (mm) \* indicates  $P < 0.001$  ▨ No support, ▩ low support, ▨ high support  
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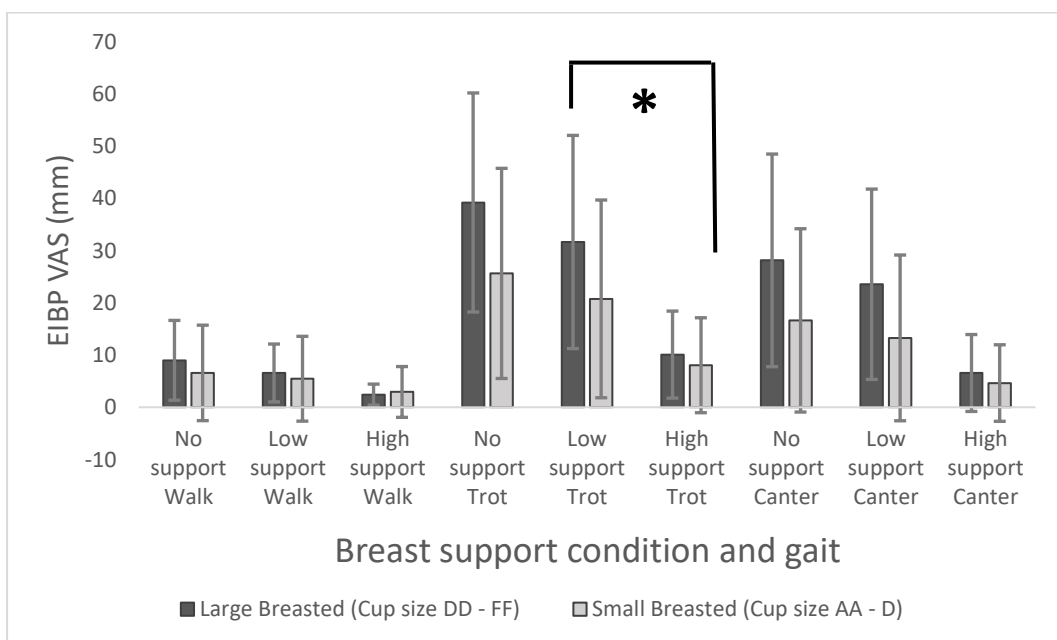
524 Figure 3 Bar chart to show impact of breast support condition on Relative Vertical Breast

525 Displacement (mm) in Large Breasted and Small Breasted groups



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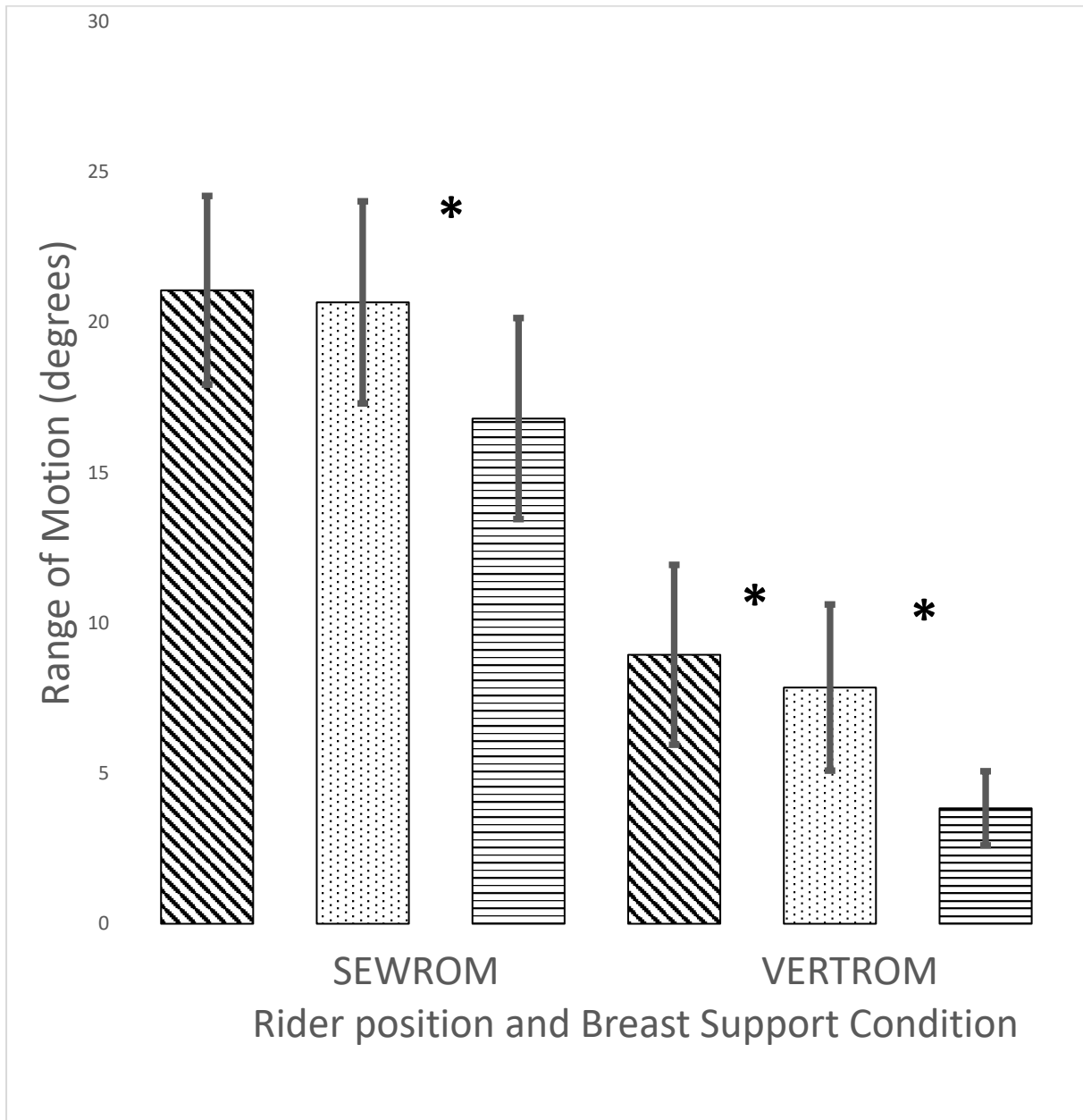
528 Figure 4 Bar chart to show impact of breast support condition (all breast sizes) on Exercise  
 529 Induced Breast Pain Visual Analogue Score (EIBP VAS) (mm) \* indicates  $P < 0.001$  ▨ No  
 530 support, ▩ low support, ▧ high support



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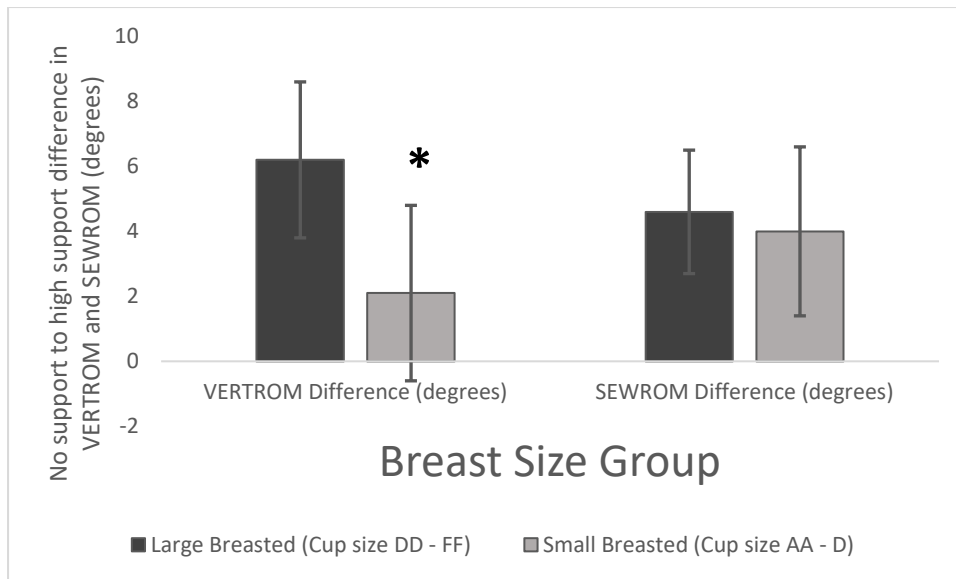
532 Figure 5 Bar chart to show impact of breast support condition on Exercise Induced Breast Pain  
533 Visual Analogue Score (EIBP VAS) (mm) in Large Breasted and Small Breasted groups \*  
534 indicates P = 0.001

535



536

537 Figure 6 Impact of Breast Support Condition on Rider Position – SEWROM and VERTROM  
538 (degrees) \* indicates P < 0.001



539

540

541 Figure 7 Bar chart to show breast size impact on rider position changes VERTROM and  
 542 SEWROM (degrees) from no support to high support conditions (median  $\pm$ IQR) \* indicates P  
 543 < 0.001

544

545 Table 1 Distribution of participant bra size (UK under band and cup size) (n = 38)

Underband (inches)	Cup size									Total
	AA	A	B	C	D	DD	E	F	FF	
32	1	1	1	1				1	1	<b>6</b>
34			2	1	5	3	5	2		<b>18</b>
36			3	1	1	2	3	4		<b>14</b>
<b>Total</b>	<b>1</b>	<b>1</b>	<b>6</b>	<b>3</b>	<b>6</b>	<b>5</b>	<b>8</b>	<b>7</b>	<b>1</b>	<b>38</b>

546

547 Table 2 Impact of support condition, breast size and gait on RVBD (mm) and EIBP VAS (mm)

RVBD (mm)				EIBP VAS (mm)			
Factors	df	F	p	Factors	df	F	p
Gait	2	289.57	<0.001*	Gait	2	44.32	<0.001*
Support condition	2	136.9	<0.001*	Support condition	2	34.69	<0.001*
Breast size	1	34.49	<0.001*	Breast size	1	15.44	<0.001*
Gait*Breast size	2	1.53	0.219	Gait*Breast size	2	3	0.051
Condition*Breast size	2	4.65	0.010*	Condition*Breast size	2	2.29	0.102
Gait*Support Condition	4	25.82	<0.001*	Gait*Support Condition	4	4.63	0.001*
Gait*Support Condition*Breast size	4	0.31	0.87	Gait*Support Condition*Breast size	4	0.31	0.87

548

549 Table 3 Impact of support condition and breast size on SEWROM (degrees) and VERTROM  
550 (degrees)

Factors	<i>df</i>	<i>F</i>	<i>p</i>	Factors	<i>df</i>	<i>F</i>	<i>p</i>
<b>SEW ROM (degrees)</b>				<b>VERT ROM (degrees)</b>			
Support condition	2	19.19	<0.001*	Support condition	2	63.42	<0.001*
Breast size	1	3.3	0.072	Breast size	1	43.89	<0.001*
Support condition*Breast size	2	0.09	0.912	Support condition*Breast size	2	8.07	0.001*

551