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Cameron, Lorna; Burbage, J.; Lewis, Victoria; Dumbell, Lucy; Billingsley, E.; Young, K.; King-Urbin, C.; Goater, F.

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

3 *Cameron, L.J.*^{1&3}, Burbage, J.², Lewis, V.³, Dumbell, L.³, Billingsley, E.¹, Young, K.¹, King*
4 *– Urbin, C.⁴ and Goater, F.¹*

5 ¹ *University Centre Sparsholt, Winchester, Hampshire, SO21 2NF, UK.*

6 ² *School of Sport, Health and Exercise Science, University of Portsmouth, Spinnaker Building, PO1*
7 *2ER, UK.*

8 ³ *Hartpury University, Gloucester, GL19 3BE, UK.*

9 ⁴ *University of Limerick, Limerick, V94 T9PX, Ireland*

10 **Corresponding author – lorna.cameron@sparsholt.ac.uk*

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

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 ± 3.11) than the small-
218 breasted group (5.5 degrees ± 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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382 **Reference List**

383 Alexander, J., Hobbs, S.J., May, K., Northrop, A., Brigden, C. and Selfe, J. (2015) Postural
384 characteristics of female dressage riders using 3D motion analysis and the effects of an athletic
385 taping technique: A randomised control trial. *Physical Therapy in Sport*, 16, 154 – 161.

386 BETA (2019) BETA National Equestrian Survey 2019 reveals an increase in riding. Retrieved
387 from [https://beta-uk.org/pages/news-amp-events/news/beta-national-equestrian-survey-2019-](https://beta-uk.org/pages/news-amp-events/news/beta-national-equestrian-survey-2019-reveals-an-increase-in-riding.php)
388 [reveals-an-increase-in-riding.php](https://beta-uk.org/pages/news-amp-events/news/beta-national-equestrian-survey-2019-reveals-an-increase-in-riding.php)

389 Burbage, J., Cameron, L.J. and Goater, F. (2016) The effect of breast support on vertical breast
390 displacement and breast pain in female riders across equine simulator gaits. *The Journal of Veterinary*
391 *Behavior*, 15, 81.

392 Burbage, J. and Cameron, L.J. (2017) An investigation into the prevalence and impact of breast pain,
393 bra issues and breast size on female horse riders, *Journal of Sports Sciences*, 35 (11), 1091-1097

394 Burbage, J. and Cameron, L.J. (2018) An investigation of bra concerns and barriers to participation in
395 horse riding. *Comparative Exercise Physiology*, 14 (1), 1 – 10.

396 Burnett, E., White, J. and Scurr, J. (2015) The Influence of the Breast on Physical Activity Participation
397 in Females. *Journal of Physical Activity and Health*, 12 (4), 588 – 594.

398 Brown, N. and Scurr, J. (2016): Do women with smaller breasts perform better in long-distance
399 running? *European Journal of Sport Science*, DOI: 10.1080/17461391.2016.1200674

400 Brown, N., White, J., Brasher, A. and Scurr, J. (2014). The experience of breast pain (mastalgia) in
401 female runners of the 2012 London Marathon and its effect on exercise behaviour. *British Journal of*
402 *Sports Medicine*, 48, 320–325.

403 Clayton, H.M. and Hobbs, S.J. (2017) The role of biomechanical analysis of horse and rider in
404 equitation science. *Applied Animal Behaviour Science*, 190, 123 – 132.

405 Douglas, J.L., Price, M. and Peters, D.M. (2012) A systematic review of physical fitness, physiological
406 demands and biomechanical performance in equestrian athletes. *Comparative Exercise Physiology*, 8
407 (1), 53 – 62.

408 Dumbell, L., Motyl, I., Douglas, J.L., Lewis, V. and Murphy, D. (2015) A preliminary comparison of
409 rider position between a horse simulator and a live horse. *Proceedings of the International Society of*
410 *Equitation Science Conference, 2015, Vancouver.*

411 Dyson, S. (2017) Equine performance and equitation science: Clinical issues. *Applied Animal*
412 *Behaviour Science*, 190, 5 – 17.

413 Eckardt, F. and Witte, F. (2017) Horse–Rider Interaction: A New Method Based on Inertial
414 Measurement Units. *Journal of Equine Veterinary Science*, 55, 1 – 8.

415 Egenvall, E., Byström, A., Roepstorff, L., Rhodin, M., Weishaupt, M.A., van Weeren, R. and Clayton,
416 H.M. (2020) Withers vertical movement asymmetry in dressage horses walking in different head-neck
417 positions with and without riders. *The Journal of Veterinary Behavior*, 36, 72 – 83.

418 Federation Equestre Internationale (2020) Dressage Tests. [https://inside.fei.org/fei/your-](https://inside.fei.org/fei/your-role/organisers/dressage/tests)
419 [role/organisers/dressage/tests](https://inside.fei.org/fei/your-role/organisers/dressage/tests)

420 Guire, R., Mathie, H., Fisher, M. and Fisher, D. (2017) Riders' perception of symmetrical pressure on
421 their ischial tuberosities and rein contact tension whilst sitting on a static object. *Comparative Exercise*
422 *Physiology*, 13 (1), 7 – 12.

423 Gunst, S., Dittmann, M.T., Arpagaus, S., Roepstorff, C., Latif, S.N., Klaassen, B., Pauli, C.A., Bauer,
424 C.M. and Weishaupt, M.A. (2019) Influence of Functional Rider and Horse Asymmetries on Saddle
425 Force Distribution During Stance and in Sitting Trot. *Journal of Equine Veterinary Science*, 78, 20 –
426 28.

427 Greve, L. and Dyson, S.J. (2014) The interrelationship of lameness, saddle slip and back shape in the
428 general sports horse population. *Equine Veterinary Journal*, 46, 687-694.

429 Haake, S. and Scurr, J. (2011). A method to estimate strain in the breast during exercise. *Sports*
430 *Engineering*, 14, 49–56.

431 Hausberger, M., Gautier, E., Biquand, V., Lunel, C. and Jégo, P. (2009) Could Work Be a Source of
432 Behavioural Disorders? A Study in Horses. *PLoS ONE*, 4 (10), 2 – 8.

433 Hockenull, J. and Creighton, E. (2012) Equipment and training risk factors associated with ridden
434 behaviour problems in UK leisure horses. *Applied Animal Behaviour Science*, 137, 36 - 42.

435 Kang, O.D., Ryu, Y.C., Ryew, C.C, Oh, W.Y., Lee, C.E. and Kang, M.S. (2010) Comparative analyses
436 of rider position according to skill levels during walk and trot in Jeju horse. *Human Movement Science*
437 29, 956–963.

438 Lewis, V. and Baldwin, K. (2018) A preliminary study to investigate the prevalence of pain in
439 international event riders during competition in the United Kingdom. *Comparative Exercise*
440 *Physiology*, 14(3), 173-181.

441 Lewis, V. and Kennerley, R. (2017) A preliminary study to investigate the prevalence of pain in elite
442 dressage riders during competition in the United Kingdom. *Comparative Exercise Physiology*, 13(4),
443 259-263.

444 MacKechnie-Guire, R., MacKechnie-Guire, E., Fairfax, V., Fisher, M., Hargreaves, S. and Pfau, T.
445 (2020) The Effect That Induced Rider Asymmetry Has on Equine Locomotion and the Range of Motion
446 of the Thoracolumbar Spine When Ridden in Rising Trot. *Journal of Equine Veterinary Science*, 88,
447 102946.

448 Martin, P., Cheze, L., Pourcelot, P., Desquilbet, L., Duray, L. and Chateau, H. (2016) Effect of the rider
449 position during rising trot on the horse's biomechanics (back and trunk kinematics and pressure under
450 the saddle). *Journal of Biomechanics*, 49, 1027 – 1033.

451 Mason, B., Page, K. and Fallon, K. (1999). An analysis of movement and discomfort of the female
452 breast during exercise and the effects of breast support in three cases. *Australian Journal of Science and
453 Medicine in Sport*, 2, 134–144.

454 McGhee, D.E and Steele, J.R. (2020) Biomechanics of Breast Support for Active Women. *Exercise and
455 Sport Sciences Reviews*, 48 (3), 99-109.

456 McLean, A.N. and Christensen, J.W. (2017) The application of learning theory in horse training.
457 *Applied Animal Behaviour Science*, 190, 18 – 27.

458 McCool, W.F., Stone-Condry, M. and Bradford, H.M. (1998). Breast health care: A review. *Journal of
459 Nurse-Midwifery*, 43 (6), 406–430.

460 McGreevy, P.D. and McLean, A.N. (2009) Punishment in horse-training and the concept of ethical
461 Equitation. *The Journal of Veterinary Behavior*, 4, 193 – 197.

462 Milligan, A., Mills, C., Corbett, J. and Scurr, J. (2015) The influence of breast support on torso, pelvis
463 and arm kinematics during a five kilometer treadmill run. *Human Movement Science*, 42, 246 – 260.

464 Mills, C., Loveridge, A., Milligan, A. and Scurr, J. (2016) Trunk marker sets and the subsequent
465 calculation of trunk and breast kinematics during treadmill running. *Textile Research Journal*, 86 (11),
466 1128–1136.

467 Nevison, C.M. and Timmis, M.A. (2013) The effect of physiotherapy intervention to the pelvic region
468 of experienced riders on seated postural stability and the symmetry of pressure distribution to the saddle:
469 A preliminary study. *Journal of Veterinary Behavior*, 8 (4), 261 – 264.

470 Norris, M., Mills, C., Sanchez, A. and Wakefield-Scurr, J. (2020) Do static and dynamic activities
471 induce potentially damaging breast skin strain? *BMJ Open Sport & Exercise Medicine*, 6: e000770.
472 doi:10.1136/bmjsem-2020-000770

473 Nylund, L.E., Sinclair, P.J., Hitchens, P.L. and Cobley, S. (2019) Do riders who wear an air jacket in
474 equestrian eventing have reduced injury risk in falls? A retrospective data analysis. *Journal of Science
475 and Medicine in Sport*, 22, 1010 – 1013.

476 Page, K. A. and Steele, J. R. (1999). Breast motion and sports brassiere design. Implications for future
477 research. *Sports Medicine*, 27 (4), 205–211.

478 Pierard, M., McGreevy, P. and Geers, R. (2019) Reliability of a descriptive reference ethogram for
479 equitation science. *The Journal of Veterinary Behavior*, 29, 118 – 127.

480 Randle, H., Edwards, H. and Button, L. (2010) The effect of rider position on the stride and step length
481 of the horse at canter. *Journal of Veterinary Behaviour*, 5 (4), 219 – 220.

482 Risius, D., Milligan, A., Mills, C. and Scurr, J. (2014): Multiplanar breast kinematics during different
483 exercise modalities, *European Journal of Sport Science*, DOI: 10.1080/17461391.2014.928914

484 Scurr, J., Brown, N., Smith, J., Brasher, A., Risius, D. and Marczyk, A. (2016) The Influence of the
485 Breast on Sport and Exercise Participation in School Girls in the United Kingdom. *Journal of
486 Adolescent Health* 58, 167 – 173.

487 Scurr, J., Hedger, W., Morris, P. and Brown, N. (2014). The prevalence, severity, and impact of breast
488 pain in the general population. *The Breast Journal*, 20 (5), 508–513.

489 Scurr, J. C., White, J. L., and Hedger, W. (2011). Supported and unsupported breast displacement in
490 three dimensions across treadmill activity levels. *Journal of Sports Sciences*, 29, 55–61.

491 Scurr, J., White, J. and Hedger, W. (2009). Breast displacement in three dimensions during the walking
492 and running gait cycle. *Journal of Applied Biomechanics*, 25 (4), 322–329.

493 Sport England. (2020). Active Lives Adult Survey November 2018/19 Report. Retrieved from
494 [https://sportengland-production-files.s3.eu-west-2.amazonaws.com/s3fs-public/2020-
495 04/Active%20Lives%20Adult%20November%2018-
496 19%20Report..pdf?BhkAy2K28pd9bDEz_NuisHl2ppuqJtpZ](https://sportengland-production-files.s3.eu-west-2.amazonaws.com/s3fs-public/2020-04/Active%20Lives%20Adult%20November%2018-19%20Report..pdf?BhkAy2K28pd9bDEz_NuisHl2ppuqJtpZ)

497 Strunk, R., Vernon, K., Blob, R., Bridges, W. and Skewes, P. (2018) Effects of Rider Experience Level
498 on Horse Kinematics and Behavior. *Journal of Equine Veterinary Science*, 68, 68 – 72.

499 Terada, K., Clayton, H.M. and Kato, K. (2006) Stabilization of wrist position during horseback riding
500 at trot. *Equine and Comparative Exercise Physiology*, 3 (4), 179–184.

501 Warren-Smith, A.K. and McGreevy, P.D. (2007) The use of blended positive and negative
502 reinforcement in shaping the halt response of horses (*Equus caballus*). *Animal Welfare*, 16, 481 – 488.

503 White, J. and Scurr, J. (2012) Evaluation of professional bra fitting criteria for bra selection and fitting
504 in the UK. *Ergonomics*, 55 (6), 704-711.

505 White, J. L., Scurr, J. C. and Smith, N. A. (2009). The effect of breast support on kinetics during over
506 ground running performance. *Ergonomics*, 52, 492–498.

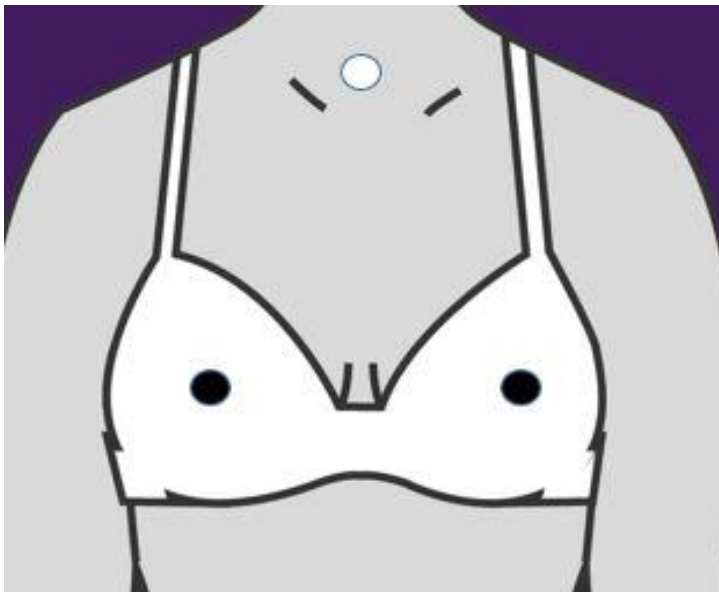
507 Williams, J. (2013) Performance analysis in equestrian sport. *Comparative Exercise Physiology*, 9 (2),
508 67-77.

509 Williams, J. and Barnett, K. (2013) A preliminary review of horse-rider reaction times in the equestrian
510 population. *International Journal of Performance Analysis in Sport*, 13 (3), 642-652.

511 Williams, J. and Tabor, G. (2017) Rider impacts on equitation. *Applied Animal Behaviour Science*, 190,
512 28 – 42.

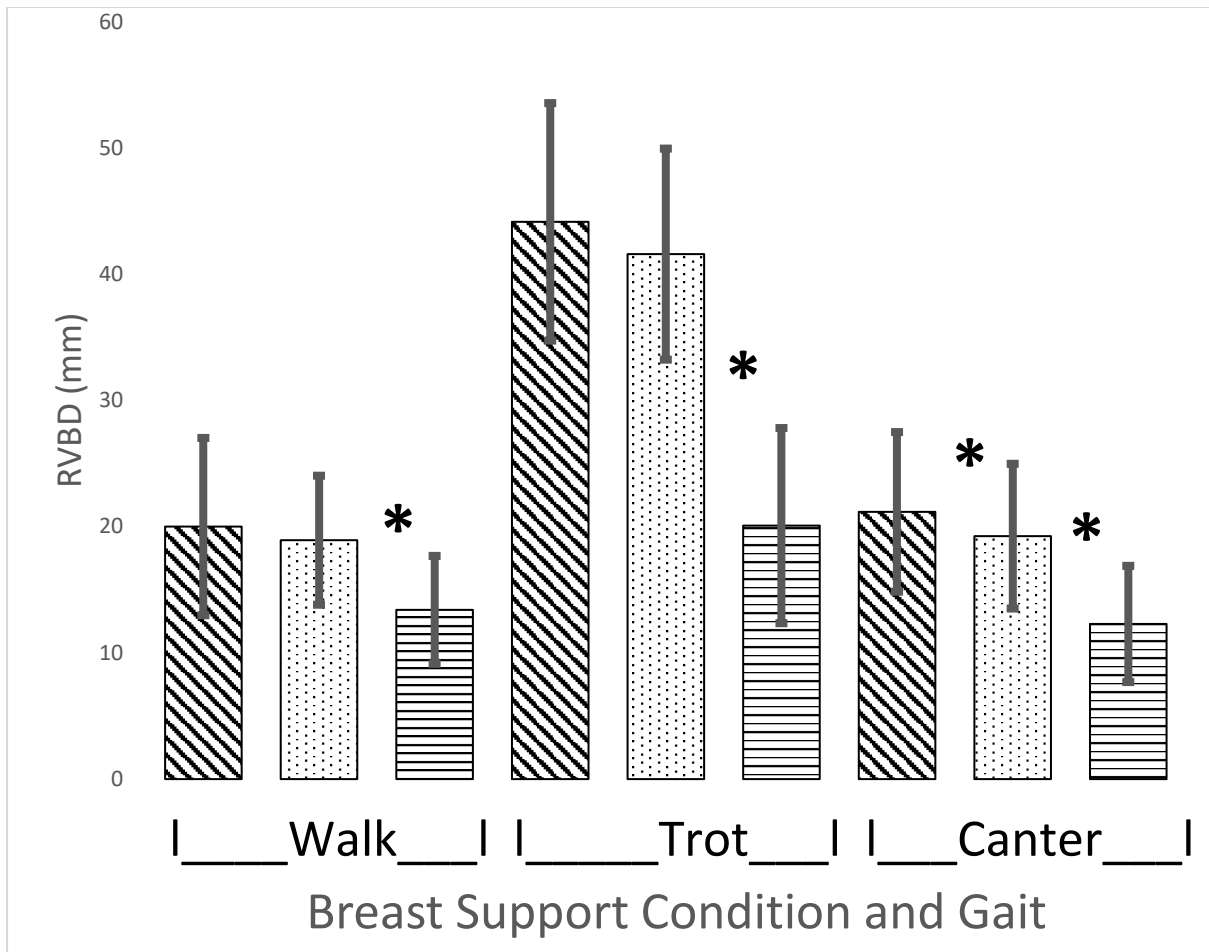
513 Wolframm, I.A. and Micklewright, D. (2010) Pre-competitive arousal, perception of equine
514 temperament and riding performance: do they interact? *Comparative Exercise Physiology*, 7 (1), 27 –
515 36.

516



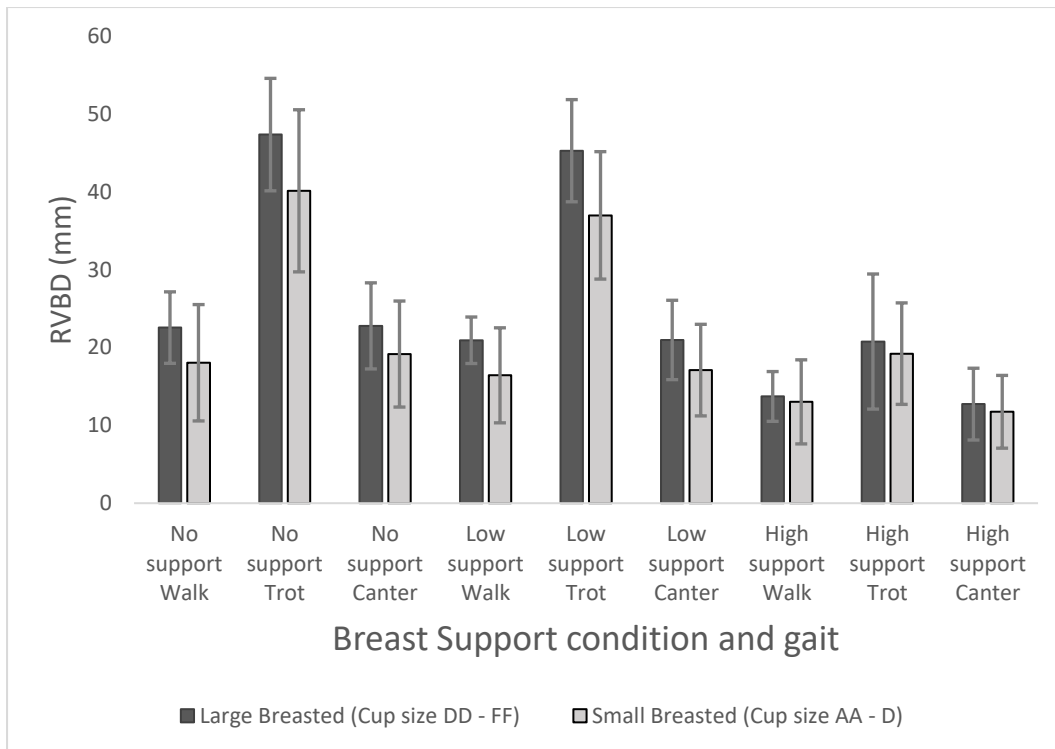
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518 Figure 1 Placement of reflective markers on each nipple and suprasternal notch



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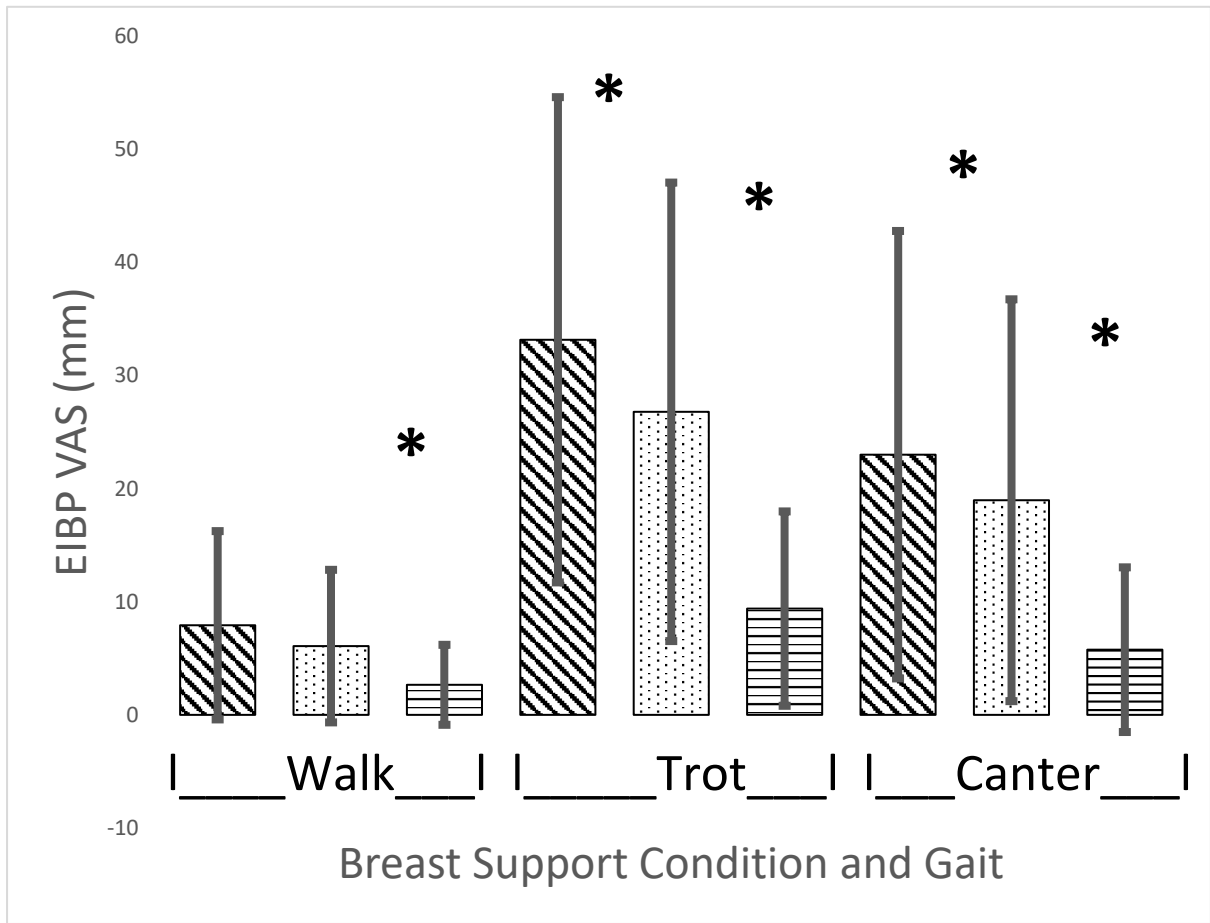
520 Figure 2 Bar chart to show impact of breast support condition (all breast sizes) on Relative
 521 Vertical Breast Displacement (mm) * indicates $P < 0.001$ ▨ No support, ▩ low support, ▨ high support
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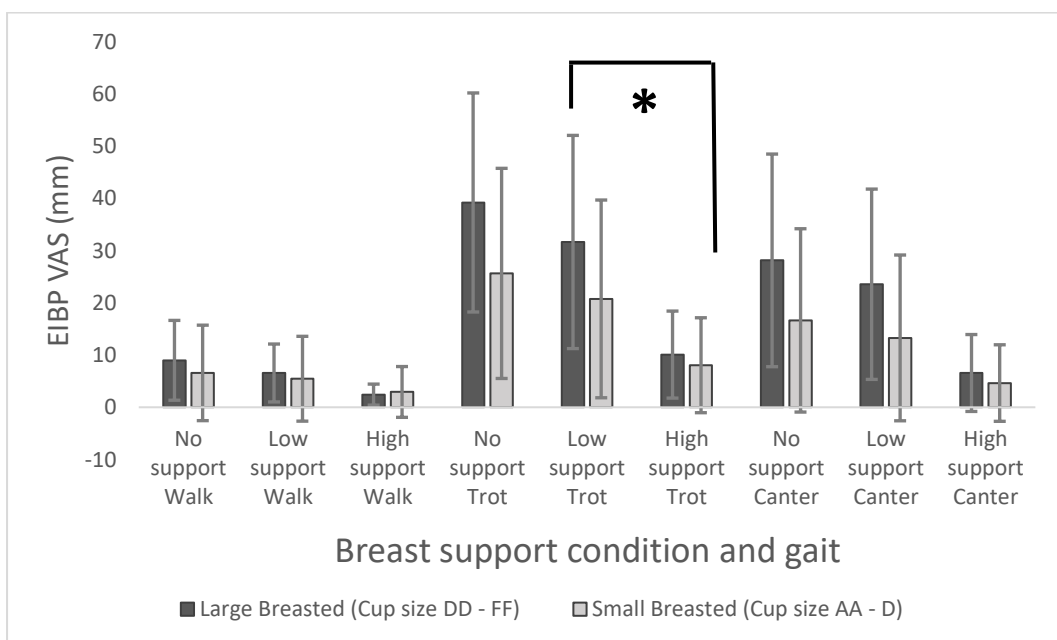
524 Figure 3 Bar chart to show impact of breast support condition on Relative Vertical Breast

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



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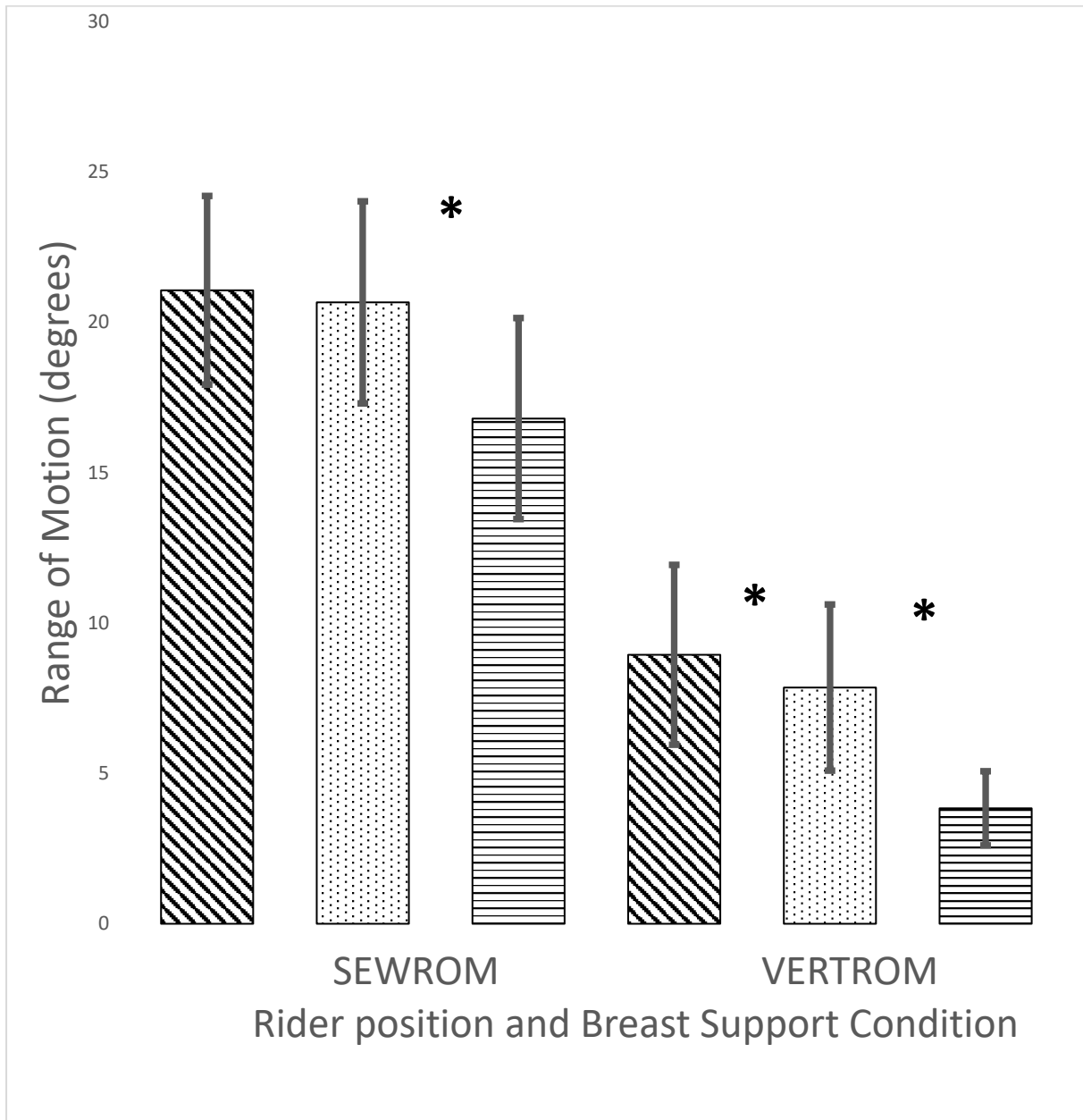
528 Figure 4 Bar chart to show impact of breast support condition (all breast sizes) on Exercise
 529 Induced Breast Pain Visual Analogue Score (EIBP VAS) (mm) * indicates $P < 0.001$ ▨ No
 530 support, ▩ low support, ▧ high support



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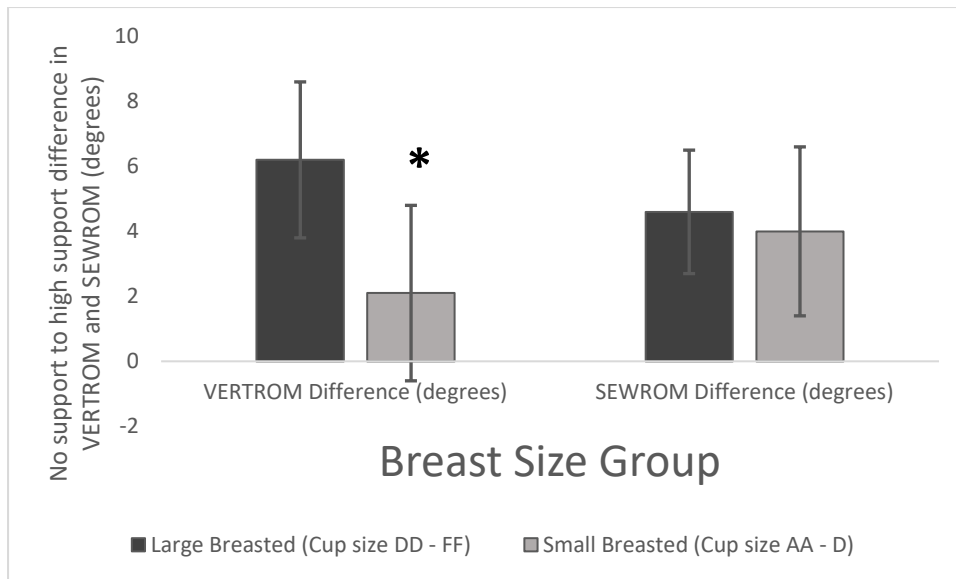
532 Figure 5 Bar chart to show impact of breast support condition on Exercise Induced Breast Pain
533 Visual Analogue Score (EIBP VAS) (mm) in Large Breasted and Small Breasted groups *
534 indicates P = 0.001

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 | 6 |
| 34 | | | 2 | 1 | 5 | 3 | 5 | 2 | | 18 |
| 36 | | | 3 | 1 | 1 | 2 | 3 | 4 | | 14 |
| Total | 1 | 1 | 6 | 3 | 6 | 5 | 8 | 7 | 1 | 38 |

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> |
|-------------------------------|-----------|----------|----------|-------------------------------|-----------|----------|----------|
| SEW ROM (degrees) | | | | VERT ROM (degrees) | | | |
| 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* |

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