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

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Running header – Female equestrian breast biomechanics

Abstract

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

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

Introduction

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

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

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

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

The prevalence of breast pain in the female horse riding population, reported as 40% (Burbage & Cameron, 2017), was slightly higher than that reported by marathon runners (Brown *et al.,* 2014). However, equestrian sports are, by nature, novel within sports science research (Williams, 2017) and findings from breast research in other sports may not be applicable. The partnership between a human and non-human athlete performing on a sporting stage is one fraught with the possibility of miscommunication and as a result, danger (Nylund *et al*., 2019). The equine member of this partnership has been the subject of much research to enhance performance and assure welfare (e.g. Pierard *et al*., 2019; Dyson, 2017; McGreevy & McLean, 2009) to the exclusion, until very recently, of the human partner. Recent developments in equestrian sport have seen winning margins at Olympic and World Championship level reduce to very small amounts, often less than one penalty point or percentage, dependent on discipline triggering more interest in the marginal gains (Williams, 2013) that may be achievable by minimal adjustments to the performance, skill, balance or emotional state of the rider (Engenvall *et al*., 2020; Martin *et al*., 2016; Strunk *et al*., 2018; Wolframm & Micklewright, 2010). This increased interest in rider performance has led to an upsurge in research considering the impact of a range of factors on the overall ability of the rider to perform at their optimal level (Clayton & Hobbs, 2017).

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

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

Materials and Methods

Following institutional ethical approval, 38 female recreational horse riders between the ages of 18 and 39 years old (to reduce the impact of age related breast changes), with bra sizes ranging from a UK 32 to 36 band size and between AA and FF cup size (Table 1) were recruited from the local equestrian community, college students and staff via word of mouth, posters and social media. Due to the changes in the breast caused by pregnancy, breast feeding and surgery (McCool *et al*., 1998; Page & Steele, 1999) participants were excluded if they were currently pregnant, had breast-fed within the last year or had previously undergone breast surgery. Bra fitting was applied to all participants according to professional best-fit criteria (White & Scurr, 2012) and allocated to a "large-breasted" group (Cup size DD – FF) (n = 21) or a "small-breasted" group (Cup size AA – D) (n = 17), as determined in previous research (Burbage & Cameron, 2017). Each participant completed a 120 second habituation on the Racewood™ Equine Simulator, comprised of 30 seconds at medium walk, 30 seconds at medium trot (sitting), 30 seconds at medium canter right and 30 seconds at medium canter left. Participants completed three trials with high, low, or no breast support. The order of breast support conditions were randomly allocated (other than no support which involved riding bare breasted), either an everyday bra considered "low support" in previous studies (White *et al*., 2009) (plain, non-padded, underwired T-shirt bra, made from 78% polyamide and 22% elastane; Marks & Spencer™) or riding bra considered "high support" (padded, underwired riding bra, made from 75% polyamide and 25% elastane, Berlei™) chosen as the only bra specifically marketed for horse riding in the UK. Reflective markers (B&L Engineering Reflective Markers 9.5mm sphere, base 17mm hard plastic) were positioned on each nipple, over the bra when worn, and the suprasternal notch (Mason *et al*., 1999; Scurr *et al*., 2011; Scurr *et al*., 2009) (Figure 1). In addition, markers were placed on the acronium, lateral epicondyle of the distal humerus, radius styloid process, greater trochanter, lateral epicondyle of the distal femur and lateral malleolus on the left side of all participants (Kang *et al*., 2010). Each participant completed a total of nine trials on the Riding Simulator (Racewood™, UK) at either Quob Stables, Durley, Hampshire U.K. or Hartpury University, Gloucester, U.K. For every participant, each trial consisted of 60 seconds in medium walk, medium trot (sitting) and medium canter (right) with the final 30 seconds of each gait being video recorded (Apple Inc., USA) apart from the “no support” condition of 30 seconds in each gait, due to the associated discomfort expected and in recognition of the exposed nature of this condition, all of which was recorded. Cameras (iPad Air, Apple Inc., USA) were placed directly in front and on the left side of the rider and trials were completed in three breast support conditions, “low support” and “high support” randomly assigned and “no support”, where participants rode bare breasted, always completed last to enable participants to feel more comfortable with the data collection process before being asked to ride bare breasted. Trials took place in a secure and screened room to ensure privacy with a maximum of three female researchers present. Each bra was checked for fit on all participants before the trial commenced. Directly after every breast support condition in each gait participants rated their exercise induced breast pain on a 100mm Visual Analogue Score (VAS) from 0mm (no pain) to 100mm (extreme pain).

Table 1 here

Figure 1 here

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

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

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

Results

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

Table 2 here

Post-hoc analysis ($P < 0.0017$) revealed in the low support condition, RVBD was not significantly reduced from the no support condition in medium walk or medium trot (sitting) but was significantly reduced in medium canter ($T = -7.35$, $P < 0.001$) (Figure 2). The high support condition significantly reduced RVBD compared to the low support condition in medium walk (T = 8.89, P < 0.001), medium trot (sitting) (T = 15.88, P < 0.001) and medium canter (T = 12.27, P < 0.001) with the greatest reduction observed between low support (M = 41.59mm ± 8.36) to high support (M = 20.08mm ± 7.73) in medium trot (sitting). No influence of breast size was observed on percentage reduction of RVBD.

Figure 2 here

Figure 3 here

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

Figure 4 here

Figure 5 here

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

Table 3 here

Figure 6 here

Figure 7 here

Discussion

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

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

The horse rider also communicates cues to the horse with pressure from their hands via rein contact to the horse's mouth, with the negative reinforcement to reward a desired behaviour being the release of this pressure (McLean & Christensen, 2017). Rein contact and tension is an area of research interest (Williams & Barnett, 2013) with much attention being paid to the importance of the rider's ability to release this negative reinforcement immediately on the performance of the desired behaviour from the horse. Hausberger *et al.* (2009) states that this inability of the rider to release negative reinforcement at the appropriate time and the subsequent "work environment" for the horse is often the basis of multiple conflict behaviours expressed in competition and leisure horses. When measuring wrist stabilisation in experienced horse riders, Terada *et al.* (2006) found that there was variability in wrist position throughout the equine stride cycle, but that these experienced riders were able to stabilise the wrist, suggesting that this is an important characteristic of competent riding. In the present study, increased breast support significantly reduced the range of movement observed in the riders' shoulder-elbow-wrist angle, although this was not related to breast size, possibly creating a more controlled hand position in trot. This raises the possibility that inadequate breast support when horse riding may be negatively impacting the rider's ability to effectively release the rein contact with accurate timing, however rein tension in different breast support conditions was not measured in this study and warrants further investigation.

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

Changes observed in rider upper body position in this study may be due to the impact of breast support condition on rider pain or muscular activity. Increased breast support significantly reduced rider EIBP, particularly in the medium trot (sitting) gait where the only significant differences in rider upper body parameters were observed, however it should be noted that the variation in EIBP was large and impacted by the individual which may account for some of the variation in results. Several studies have highlighted the incidence of competitive riders preforming when in pain (Lewis & Baldwin, 2018; Lewis & Kennerley, 2017) and reporting that this pain has negatively impacted their equestrian performance. These differences in upper body positioning in trot, although statistically significant, may not be biologically significant and equine parameters in response to these changes should be monitored. Future studies should also investigate the impact of breast support, relative vertical breast displacement, breast size and EIBP on upper body muscular activity as this may be the cause of the positional changes seen and would further impact the rider's ability to communicate clearly through the rein aids (Terada *et al.*, 2006).

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

Conclusions

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

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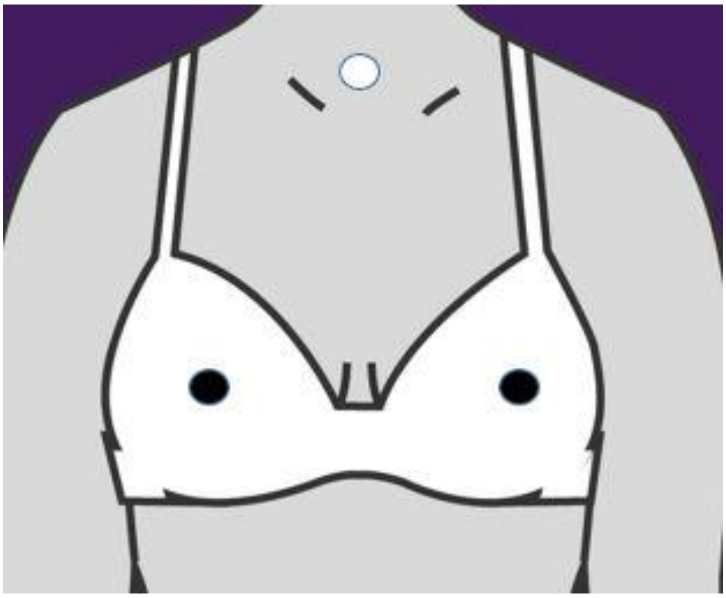

Figure 1 Placement of reflective markers on each nipple and suprasternal notch

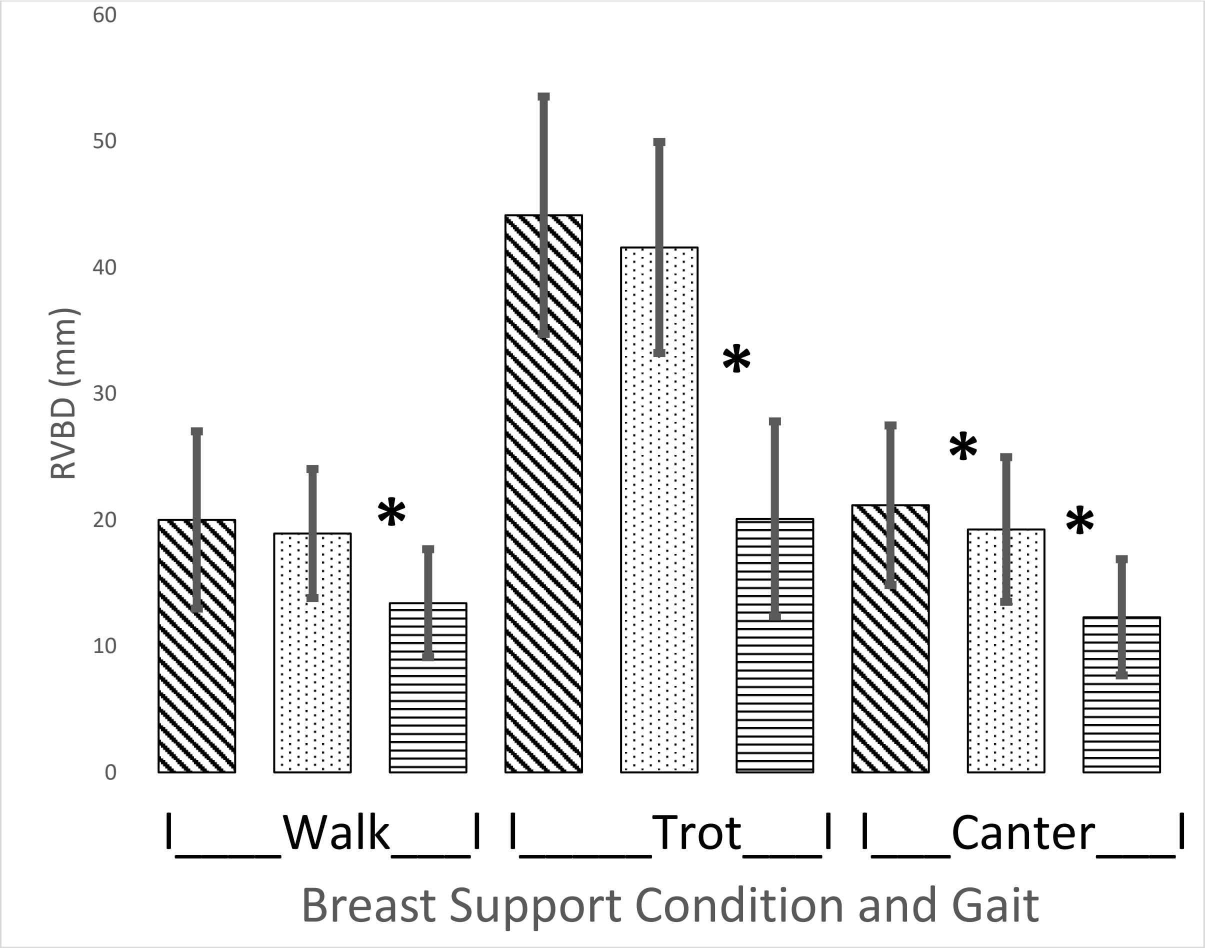

Figure 2 Bar chart to show impact of breast support condition (all breast sizes) on Relative Vertical Breast Displacement (mm) * indicates $P < 0.001$ ▧ No support, ░ low support, ▤ high support

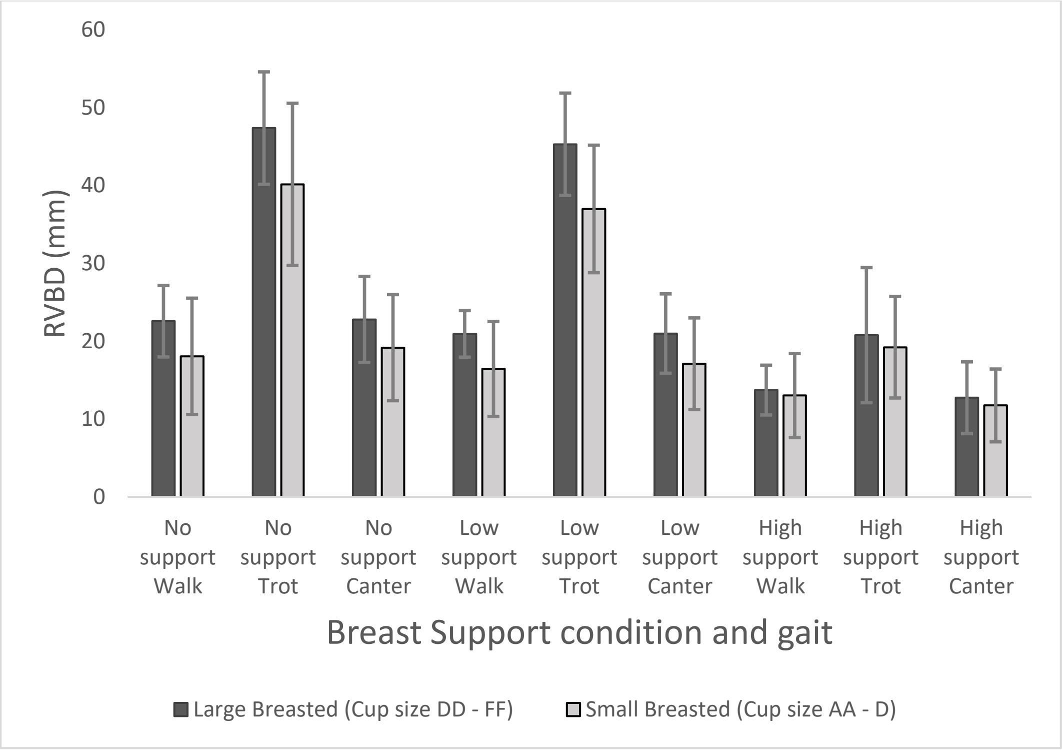

Figure 3 Bar chart to show impact of breast support condition on Relative Vertical Breast Displacement (mm) in Large Breasted and Small Breasted groups

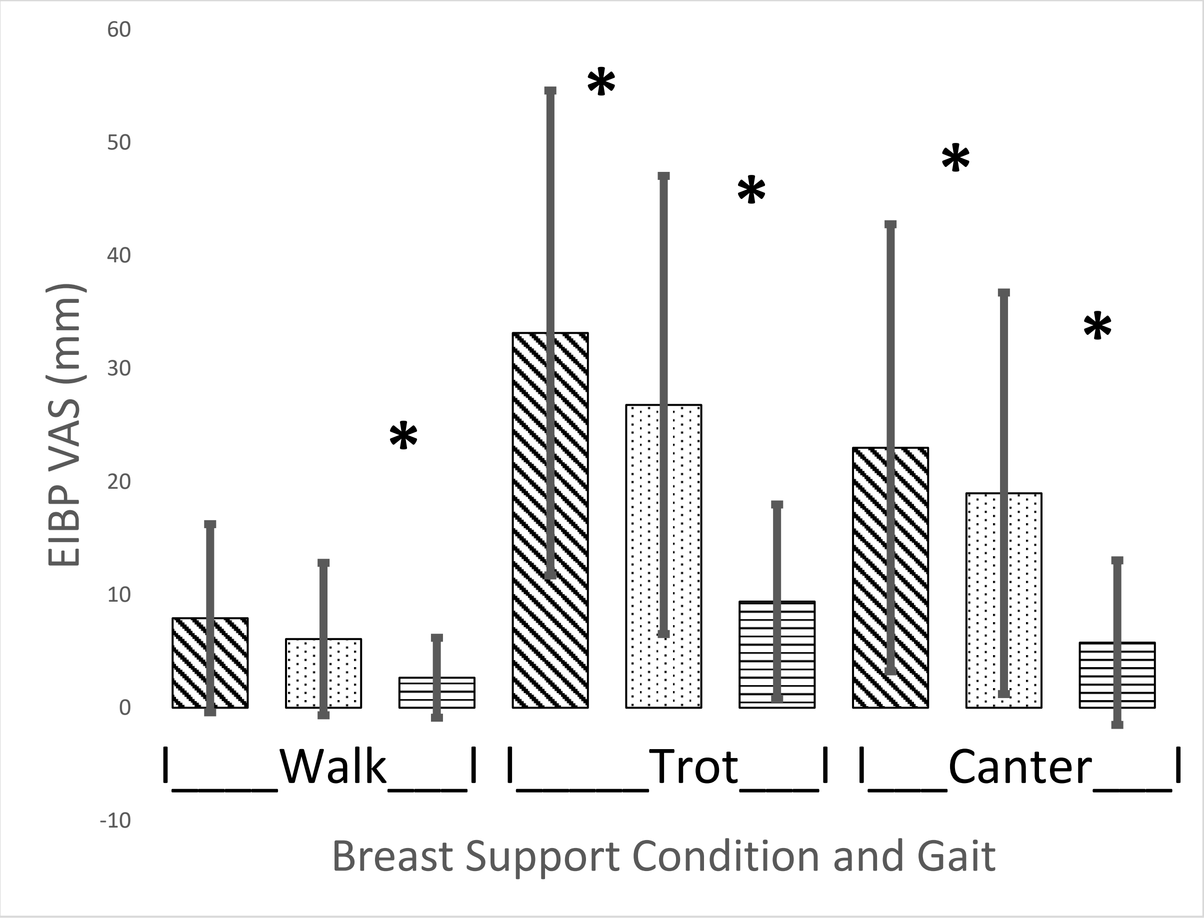

Figure 4 Bar chart to show impact of breast support condition (all breast sizes) on Exercise Induced Breast Pain Visual Analogue Score (EIBP VAS) (mm) * indicates P < 0.001 ▧ No support, ░ low support, ▤ high support

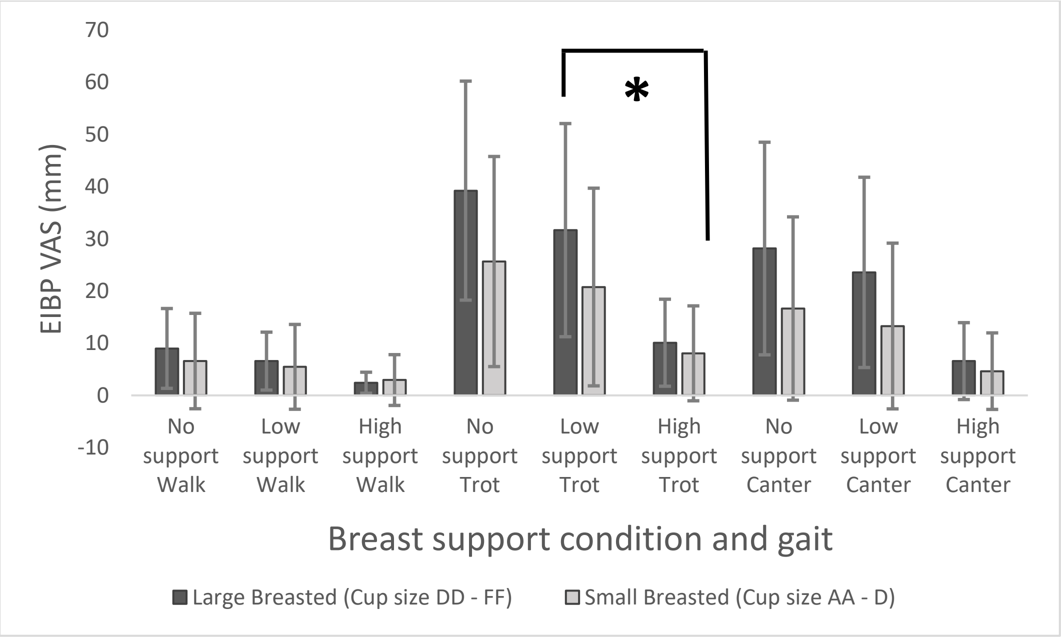

Figure 5 Bar chart to show impact of breast support condition on Exercise Induced Breast Pain Visual Analogue Score (EIBP VAS) (mm) in Large Breasted and Small Breasted groups * indicates P = 0.001

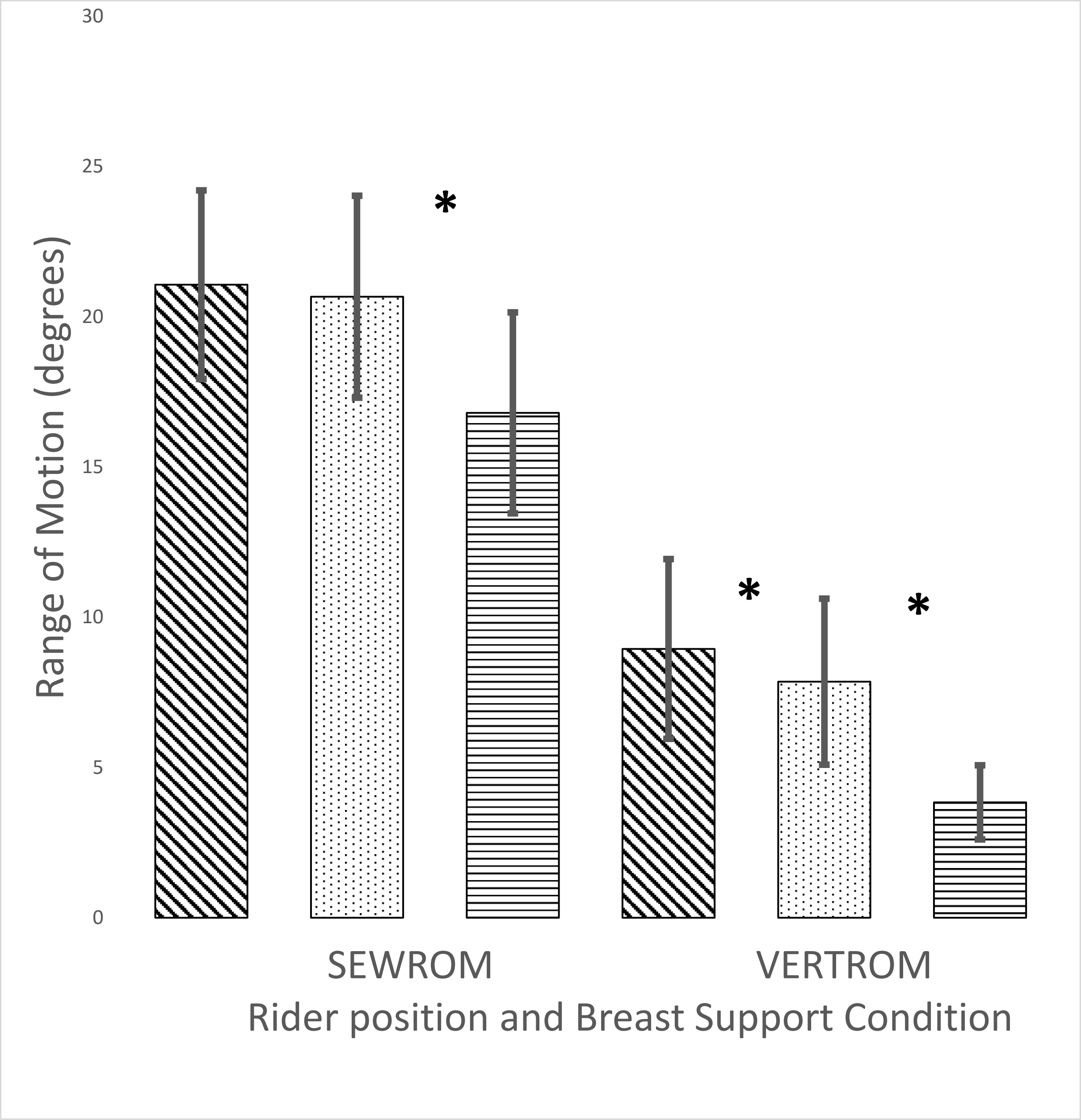

Figure 6 Impact of Breast Support Condition on Rider Position – SEWROM and VERTROM (degrees) * indicates $P < 0.001$

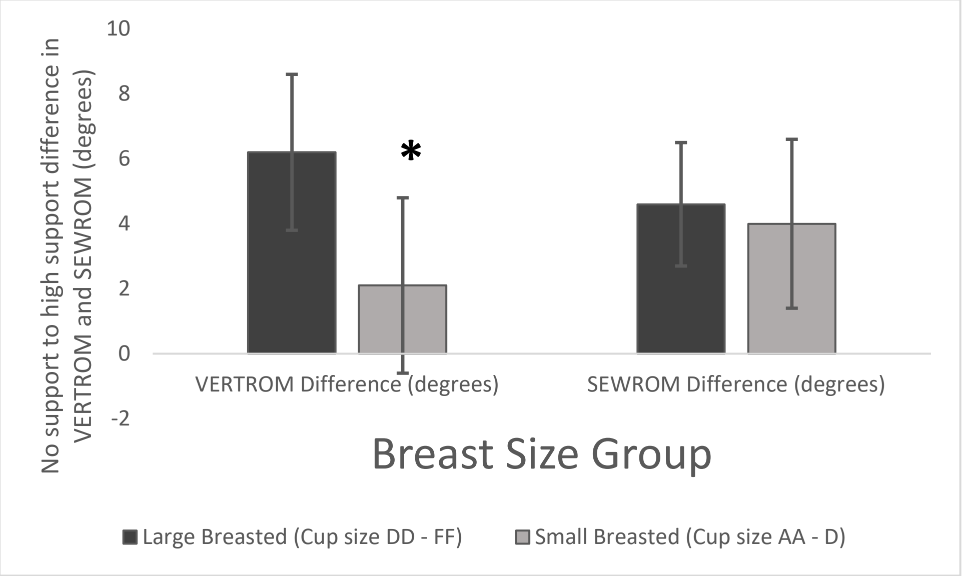

Figure 7 Bar chart to show breast size impact on rider position changes VERTROM and SEWROM (degrees) from no support to high support conditions (median ±IQR) * indicates P < 0.001

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

	Cup size									
Underband (inches)	AA	A	B	C	D	DD	E	F	FF	**Total**
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**

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

Factors	*df*	*F*	*p*	Factors	*df*	*F*	*p*
RVBD (mm)				**EIBP VAS (mm)**			
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

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

Factors	*df*	*F*	*p*	Factors	*df*	*F*	*p*
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*