There are two sides to every story: implications of asymmetry on breast support requirements for sports bra manufacturers

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This study aimed to investigate: 1) the prevalence and magnitude of breast movement asymmetry, 2) the interaction between static and dynamic breast asymmetry and 3) the influence of sports bras on breast asymmetry during running. Position data were collected from 167 females whilst treadmill running and then a sub-group of twelve participants in different bra conditions. Breast movement asymmetry existed in 89% of participants, with resultant static breast position asymmetry larger in participants displaying dynamic asymmetry. Asymmetry was most commonly caused (60 to 75%) by greater movement of the left breast. No significant relationships were found between asymmetry and bra size or breast pain. Sports bras reduced asymmetry prevalence from 75% to 33% of participants in the antero-posterior direction but only from 75% to 67% of participants in the infero-superior direction. The magnitude of range-of-motion asymmetry reduced from 67 mm with no bra to between 6 and 64 mm in-bra in the infero-superior direction, with the best performing bra incorporating encapsulating cups and adjustable straps and underband. It is recommended that sports bras allow underband and strap adjustment to facilitate individual breast support and that asymmetry is considered when designing and fitting bras, which could utilise resultant asymmetry measured statically.

Keywords: Breast Health, Garment Design, Running Gait, Kinematics

Introduction

Breast asymmetry relating to mass and shape of the breast has been reported to exist in 94% (Losken, Fishman, Denson, Moyer, & Carlson, 2005), 88% (Rohrich, Hartley, & Brown, 2006) and 18 to 55% (Brown, Ringrose, Hyland, Cole, & Brotherston, 1999) of the female population, depending on the measure. Furthermore, asymmetry of breast size and shape has previously been reported to show a positive relationship with overall breast size (Manning, Scutt, Whitehouse, & Leinster, 1997; Møller, Soler, & Thornhill, 1995). Losken et al. (2005) also indicated that it was more common for the left breast to be larger (62%) than the right (32%), with 6% showing no asymmetry in breast size. This physical asymmetry has clear implications on breast support requirements, which may differ for left and right sides due to potential asymmetry in the mass and consequently force applied by each breast. Asymmetry within the human body has also been widely reported relating to other physiological characteristics, such as limb length, and performance measures in gait (Baylis & Rzonca, 1988; Kaufman, Miller, & Sutherland, 1996; Perttunen, Anttila, Södergård, Merikanto, & Komi, 2004). Previous work investigating biomechanical asymmetry in gait has identified it to be individualistic in nature (Exell, Irwin, Gittoes, & Kerwin, 2012; Exell, Irwin, Gittoes, & Kerwin, 2017). Based on these previous studies, it is unclear whether biomechanical asymmetry in breast movement during gait would be due to greater movement of the left breast, due to the typically larger breast size, or be individual as reported in other gait asymmetry measures. In this manuscript, asymmetry is defined as any divergence from symmetry, which is identical values for left and right sides of the body (Brown et al., 1999; Exell et al., 2012; Losken et al., 2005).

The importance of correctly fitting and appropriate breast support garments during exercise is an important topic that has received attention in the literature (Brown, White, Brasher, & Scurr, 2014; Mason, Page, & Fallon, 1999; White, Mills, Ball, & Scurr, 2015; White & Scurr, 2012). However, if asymmetry is present within individuals' breast movement during running, the support requirements may differ for each breast. From a breast support perspective, information relating asymmetry in breast movement with other predictive factors such as breast size or asymmetry when standing could be beneficial in identifying when asymmetrical support may be required. Breast pain has also been identified as an important consideration for exercising women (Brown et al., 2014; Mason et al., 1999; White et al., 2015), which can reduce participation in physical activity. To the authors' knowledge, breast pain has not been investigated in relation to breast asymmetry, but asymmetry in the mass and subsequent force applied by the breasts may lead to greater pain being experienced in one breast than the other, which could influence individuals' reporting of pain. Previous studies have reported the varying effects of different bras on breast movement (Lorentzen & Lawson, 1987; Mason et al., 1999; Scurr, White, & Hedger, 2010), although it is unclear how differing bras influence breast movement asymmetry. To the authors' knowledge, the only bras that are commercially available to overcome breast asymmetry are everyday bras focussed on aesthetics and producing a symmetrical overall breast shape, rather than customising support for left and right breasts during exercise. As highlighted above, breast support to reduce breast movement is important in relation to breast pain. Therefore, asymmetry of breast movement identified during activities such as running would indicate the need for more customised breast support for each side during such activities.

Asymmetry of breast movement during running has previously been reported to exist in a preliminary study of ten 32D sized participants (Mills, Risius, & Scurr, 2015). However, no previous studies investigating breast asymmetry have considered the relationship between asymmetry when measured statically and during dynamic activities, such as running. Furthermore, the relationship between breast movement asymmetry during running and other factors such as breast size or pain have not been investigated. Given the individual nature of biomechanical asymmetry reported in running gait (Exell et al., 2017; Exell, Irwin et al., 2012), it is quite possible that individual asymmetry profiles may exist relating to dynamic breast movement. Asymmetry of breast movement during dynamic activities may have implications on breast support requirements, with asymmetry in different movement directions indicating that bras may benefit from greater adjustability to cater for this asymmetrical breast movement. Previous research investigating breast movement in different directions and breast pain during activities such as running has identified the vertical direction as having the strongest link with breast pain (Mills et al., 2015; Scurr et al., 2010).

The aims of this study were to investigate: 1) the prevalence and magnitude of kinematic breast asymmetry, 2) the interactions between static and dynamic breast asymmetry and between breast asymmetry, breast pain and bra size and 3) the influence of different sports bras on dynamic asymmetry during running. It was hypothesised that significant breast movement asymmetry would exist during dynamic activities (H_1), that it would be positively related with static breast asymmetry (H_2), bra size (H_3) and breast pain (H_4) and that wearing a sports bra would reduce breast movement asymmetry (H_5). The purpose of the study was to further current understanding of breast asymmetry and to inform bra manufacturers, athletes and researchers about the incidence of breast movement asymmetry during running. These findings may have implications on both sports bra design requirements and future breast research data collection protocols.

Methods

Prior to data collection, ethical approval was gained from the University Research Ethics Committee. All participants provided informed consent prior to their data being collected. To address the research questions of the study, two separate protocols were utilised, which are described separately and termed Collection A and Collection B. Collection A involved a descriptive analysis of asymmetry prevalence and comparison with other factors. Collection B incorporated an intervention of varying sports bras to assess the influence on breast movement asymmetry.

Collection A

Participants and protocol

To quantify the prevalence of dynamic breast movement asymmetry and relationships with static asymmetry, bra size and breast pain, data were collected from 167 female participants (25 ± 5 years, 63.3 ± 7.4 kg, 1.66 ± 0.06 m, bra size 32A - 34G), who volunteered through the department's Research Group in Breast Health. Cross-graded bra size was assessed by a trained bra fitter against published best fit criteria (McGhee & Steele, 2010; White & Scurr, 2012) during each testing session, where a change of one cross-grade size relates to an increase of one cup or underband size.

Breast and torso position data were collected using an automated motion capture system (Oqus, Qualisys®, Sweden) operating at a minimum of 100 Hz. Following calibration of the system, reflective markers were positioned on participants' suprasternal notch, left and right anterior inferior aspects of the 10th ribs and on the left and right nipples to track breast motion (Scurr, White, & Hedger, 2011). A heel marker was also used to detect touchdown events during running (Scurr et al., 2010). Participants were asked to stand so that their feet were aligned with the lab coordinate system whilst a static trial was collected. Following an individually selected warm up, participants then ran on a treadmill (H/P/Cosmos Mercury, Germany) aligned with the lab coordinate system at a treadmill speed of 2.78 m/s whilst bare-breasted. This running speed (10 km/hr) was selected as it has been frequently used in previous breast biomechanics research and is common for recreational distance running (www.parkrun.org.uk), which leads to a large number of repeated impacts over the duration of a run. Participants were asked to run for a time of 2 minutes, following which, data were collected for five complete strides (i.e. ten steps). Immediately after the running data were collected, participants rated the highest amount of exercise induced breast pain throughout the running trial on a numerical rating scale ranging from 0 (no pain) to 10 (extreme pain) (Mason et al., 1999).

Data processing and analysis

Data were reconstructed using Qualisys Track Manager software (Versions 1.10 - 2.13, Qualisys, Sweden). Marker position data were filtered using a second-order low-pass Butterworth filter with a cut- off of 13 Hz. Nipple position was calculated relative to the local coordinate system of the trunk, defined by the suprasternal notch and rib markers (Mills et al., 2015).

Using the antero-posterior velocity of the participants' heel markers, instants of touchdown were identified as the epoch when velocity changed from being positive to negative (Zeni Jr, Richards, & Higginson, 2008). Five complete strides were identified for each participant.

Data were further analysed in Matlab (R2018b, The Mathworks ®, USA). Range of motion (ROM) of each nipple marker was quantified using (1) in antero-posterior (AP), medio-lateral (ML) and infero-superior (IS) directions as well as the resultant (RT) direction.

$$ROM = S_{Max} - S_{Min} \qquad (1)$$

where S_{Max} and S_{Min} are the maximum and minimum displacement values of each nipple within a gait cycle relative to the sternal notch in the local coordinate system, respectively.

Asymmetry analysis

Asymmetry was quantified for both static and dynamic trials using the modified symmetry angle (Exell, Gittoes, Irwin, & Kerwin, 2012; Zifchock, Davis, Higginson, & Royer, 2008) presented in (2). This measure provides a normalised quantification of asymmetry where 0% indicates identical values for left and right sides and 100% indicates values of equal magnitude and opposite polarity.

$$\theta_{SYM} = \frac{|45-(\tan^{-1}X_L/X_R)|}{90} \cdot 100\% \qquad (2)$$

where θ_{SYM} is the asymmetry magnitude and X_L and X_R are the left and right values, respectively for the variable of interest. Asymmetry magnitude was quantified using (2), except where:

$$45 - (\tan^{-1} X_L/X_R) > 90$$

when (3) was substituted to correct for values >100%.

$$\theta_{SYM} = \frac{|45-(\tan^{-1}X_L/X_R)|-135}{90} \cdot 100\% \qquad (3)$$

Static asymmetry magnitude was calculated based on the mean displacement of each nipple from the sternal notch marker during the static trial. For dynamic trials, the significance of asymmetry in breast ROM was defined based on the method of Exell, Gittoes et al. (2012) using significance testing between left and right values. Following tests for normality (Shapiro-Wilks), paired samples t-tests or Wilcoxon tests were used to test for significant asymmetry for normally and non-normally distributed data, respectively (sig = 0.05).

Statistical analysis

Once asymmetry had been quantified, further statistical analyses were performed to assess the relationship between breast movement asymmetry and other variables of interest. Statistical tests were selected based on Kolmogorov-Smirnov normality testing. The number of participants demonstrating significant asymmetry for nipple displacement in each direction was calculated as the percentage of all 167 participants. Participants displaying significant asymmetry were further analysed to investigate the direction of asymmetry. For participants displaying significant asymmetry, the relationship between breast size and asymmetry was investigated via the Spearman correlation coefficient. The relationship between static and dynamic asymmetry was investigated by comparing the correlation (Pearson) between static and dynamic asymmetry magnitude for participants displaying significant dynamic asymmetry. Static asymmetry magnitude was also compared in each direction between participants that displayed significant dynamic asymmetry and those that did not, using independent t-tests (sig = 0.05). This approach was taken to consider the influence of variability across trials during dynamic movement by comparing those individuals that showed significant asymmetry between sides across all five strides. Effect sizes were quantified for the comparison of dynamic asymmetry magnitude by dividing difference in mean values by the average standard deviation (Cohen, 2013). Effect Sizes were interpreted as: trivial (< 0.2), small (0.2–0.6), moderate (0.6 –1.2) and large (>1.2) (Saunders, Pyne, Telford & Hawley, 2004).

Collection B

Participants and protocol

To address the question of whether providing breast support reduced breast movement asymmetry, a sub group of twelve participants that were a 34D bra size were randomly selected for further analysis (25 ± 5 years, 64.8 ± 6.2 kg, 1.68 ± 0.05 m). This bra size was selected for the intervention to allow comparison with previous research (Mills et al., 2015) and due to the increased prevalence of reported breast pain for cup sizes of D and larger (Lorentzen & Lawson, 1987; White, Scurr, & Smith, 2009). For the additional testing stage, position data were collected at 240 Hz using an electromagnetic motion tracking system (Micro Sensor 1.8TM, Polhemus, Colchester, Vermont, USA) allowing sensor motion to be tracked underneath the material of the bra. Six sensors were placed on participants at the following anatomical landmarks: suprasternal notch, xiphoid process, seventh cervical (C7) and eighth thoracic (T8) vertebrae and on left and right nipples. Each participant then ran on a treadmill (H/P/Cosmos Mercury, Germany) that was aligned with the sensor system's coordinate system at a speed of 2.78 m/s during four different breast support conditions, representing the range of sports bras commercially available. During each bra condition, participants were asked to run for a time of 2 minutes, following which, data were collected for ten complete strides (i.e. twenty steps). The conditions tested were:

1) Bare breasted.
2) Bra 1 - a high support nylon sports bra with an adjustable underband, adjustable straps in a cross-back strap configuration and encapsulating cup support.
3) Bra 2 - a medium supporting polyester sports bra without adjustable straps or underband, a racer back strap configuration and compression style support.
4) Bra 3 - a high supporting polyester sports bra with an adjustable underband, non-adjustable straps in a racer back configuration and encapsulating cup support.

Data processing and analysis

Position data of each sensor were calculated relative to the electromagnetic system's base station and were used to define the position of each nipple relative to the local coordinate system of the trunk, as in Collection A. Position data were filtered using a second-order low-pass Butterworth filter with a cut- off of 13 Hz. The trunk segment was defined based on ISB recommendations (Wu et al., 2005) between the mid-point of the suprasternal notch and C7 markers and the mid-point of the xiphoid process and PX and T8 markers.

The IS axis was defined along the vector connecting the ends of the segment, the AP axis was determined by the vector that is perpendicular to both the plane defined by the four segment markers and the IS axis. The ML axis was then determined using the right-hand rule. Nipple position was calculated relative to the local coordinate system of the trunk. Due to the smaller field of view of the sensor system used to allow position to be tracked underneath the bra, it was not possible to position a marker on the heel. Therefore, running strides were identified using the peak maximum IS position of the marker located on the suprasternal notch.

Asymmetry analysis

Asymmetry significance was quantified as in Collection A using the method of Exell, Gittoes et al. (2012). The number of participants displaying significant asymmetry was calculated during each bra condition. Of the participants displaying significant symmetry, the largest range of motion asymmetry was recorded for each condition.

Results

Collection A

Dynamic asymmetry prevalence for nipple range of motion within all participants is presented in Table 1. In total, 149 participants (89%) demonstrated significant dynamic breast asymmetry in at least one direction. More than half of the participants displayed significant asymmetry in breast range of motion for all directions tested with most occurrences of asymmetry (106) occurring in the IS direction. Mean asymmetry magnitude was 16%, 13%, 10% and 11% for AP, ML, IS and RT directions, respectively. The largest differences in mean range of motion of the left and right nipples for individual participants were 58 mm, 70 mm, 33 mm and 29 mm for the AP, ML, IS and RT directions, respectively. Table 1 also includes results for the direction of asymmetry, which showed that a larger range of motion most often occurred in the left breast for participants that displayed significant asymmetry. Differences in bra size between asymmetrical and non-asymmetrical participants were small with the largest difference being 0.24 cross grade magnitudes for the ML direction, where a value of 1 indicates an increase of one cup or underband size.

Static nipple position asymmetry magnitudes are presented in Table 2. Mean (±SD) asymmetry values are presented for participants that displayed significant asymmetry during the dynamic trials and those that did not, allowing variability between strides to be considered by comparing participants that did and did not display significant asymmetry across all five strides. Static asymmetry was only significantly different between dynamic asymmetry groups in the resultant direction, with a small effect size (Table 2).

Relationships between dynamic asymmetry magnitude, breast size and breast pain are presented in Table 3 for participants that displayed significant range of motion asymmetry in each direction during running. No significant correlations were found, with the largest ρ correlation magnitude being 0.18, indicating a weak relationship between asymmetry magnitude and bra size.

Collection B

Table 4 includes the number of participants of the sub-group that displayed significant range of motion asymmetry during each bra condition. Asymmetry was prevalent in all directions; however, the direction with the most participants displaying asymmetry varied across support. The largest asymmetry prevalence was reported during the no bra condition, followed by the Bra 2, which reduced the number of asymmetrical participants by one in the ML and IS directions. The bra that reduced the number of participants displaying significant asymmetry the most was Bra 1, which eliminated significant asymmetry for all but two in the AP direction and seven in the IS direction.

The mean and largest magnitudes of range of motion asymmetry for each condition and direction are shown in Table 5. For all directions, the largest asymmetry was present in the no bra condition, with RT values of up to 80 mm. Largest resultant range of motion asymmetry was reduced to 5 mm for Bra 1 and 21 mm for Bra 2; however, Bra 3 still demonstrated a maximum asymmetry of 71 mm.

Discussion and Implications

The aims of this study were to investigate 1) the prevalence and magnitude of kinematic breast asymmetry, 2) the interactions between static and dynamic breast asymmetry and between breast asymmetry, breast pain and bra size and 3) the influence of sports bras on dynamic asymmetry during running. Results demonstrate that asymmetry of breast movement was present in one or more direction in almost 90% of the 167 women tested during running, therefore accepting H_1. The most prevalent direction of breast movement asymmetry was the IS direction, with over half (63%) of the participants demonstrating this, which is the direction most strongly linked with breast pain in previous studies (Mills et al., 2015; Scurr et al., 2010). These results support the finding of asymmetry in breast movement reported by Mills et al. (2015); however, asymmetry prevalence was lower in the large group of participants examined in the current study than the group initially investigated in the preceding study. Other than the larger sample size in the current study, which may provide a more representative sample of the population, another possible reason for the smaller number of participants being classed as displaying asymmetrical movement in this study is the inclusion of a range of participants with different breast sizes. Breast sizes in the current study ranged from 32A to 34G, compared to the single size of 32D included in the previous study of Mills et al. (2015).

The asymmetry of breast movement reported in 89% of participants indicates that the support requirements may differ between the left and right breast for the majority of the female population. From a practical perspective, this difference in support requirements is important when considering bra fitting (Brown et al., 2014; Mason et al, 1999; White et al., 2015; White & Scurr, 2012) and design. Therefore, during fitting, support should be refined for each side to minimise breast movement during dynamic activity. The side demonstrating greater movement was most often the left side, supporting previous research that has indicated that the left breast is larger (Losken et al., 2005). However, not all participants showing asymmetry demonstrated greater movement on the left side. Therefore, it is recommended that asymmetry be considered on an individual basis, in agreement with previous findings relating to static breast asymmetry (Brown et al., 1999).

Static breast asymmetry did not significantly differ between asymmetrical and non-asymmetrical participants during the dynamic activity when considering component positions. However, in the RT direction, a significant difference (with small effect size) in static asymmetry was reported between dynamically asymmetrical and non-asymmetrical participants. Therefore, H_2 was partially accepted as a positive link was evident between RT static breast asymmetry and dynamic asymmetry. When investigating breast movement asymmetry magnitude and breast size, no meaningful relationship was found between the two; therefore, H_3 was rejected. In addition, there was no significant difference in the magnitude of breast size for participants displaying asymmetry and those that did not, suggesting that a participant's overall breast size does not lead to greater asymmetry prevalence. These findings conflict with previous research that has investigated breast size and asymmetry of static breast shape (Manning et al., 1997; Møller et al., 1995), which reported greater asymmetry in larger breasts. It is suggested that this difference in findings is due to the previous studies investigating static asymmetry and the current study investigating asymmetry during dynamic activity, when breast movement is maximised. The important differences in findings during dynamic activity compared with static measures indicates that, whilst both static and dynamic breast asymmetry has been reported to exist, it may not be possible to predict dynamic breast asymmetry by overall breast size or static asymmetry of nipple position measured in each component direction. However, in the current study, a significant difference (with small effect) was evident for static position asymmetry in the RT direction between participants that did and did not display dynamic breast asymmetry when running. Based on these results, it is recommended that, if it is not possible to include dynamic activity when fitting or assessing sports bras, the difference in RT magnitude of the separation from nipple to sternal notch may be a suitable measure to indicate dynamic breast asymmetry; however this should be interpreted with caution based on the small effect.

Breast pain did not show any meaningful relationship with asymmetry, therefore, rejecting H_4. The lack of relationship between the two variables suggests that asymmetry doesn't influence overall reported breast pain. A limitation with the reporting of breast pain used in this study was that overall breast pain was assessed, rather than pain being reported specific to left and right breasts. Future work could further understanding in this area by assessing which breast causes the greatest amount of pain to investigate whether this is linked to asymmetrical movement.

Regarding the influence of bras on dynamic asymmetry, the number of participants displaying significant asymmetry reduced in all bra conditions by varying amounts. The largest reduction in the number of asymmetrical participants was consistently achieved by Bra 1 (encapsulation), where the number of asymmetrical participants reduced from nine to four for the AP direction and from eight to six in the RT direction. In the IS direction, which has been most strongly linked with breast pain, the number of participants showing significant asymmetry only reduced from nine to eight when wearing Bra 1 or Bra 3 (both encapsulation) compared to the no bra condition; however, the magnitude of asymmetry was greatly reduced when wearing Bra 1. The worst performing bra in terms of reducing breast movement asymmetry was Bra 2 (compression), that only reduced asymmetry prevalence in the ML direction by one participant and increased asymmetry in the RT direction. Bra 3 reduced asymmetry prevalence compared with Bra 2; however, the magnitude of asymmetry was larger in Bra 3. When considering magnitude of asymmetry in range of motion, Bra 1, again performed the best. The general trend was for asymmetry prevalence and magnitude to reduce in bra conditions; therefore, H_5 was accepted. The improved performance of Bra 1 compared with Bras 2 and 3 in reducing asymmetry suggests that the inclusion of adjustable straps and an adjustable underband is an important factor allowing breast support to be customised for each breast resulting in reduced asymmetry of breast movement. Furthermore, the encapsulation styles of Bra 1 and Bra 3 appeared to be more effective at reducing asymmetry prevalence than the compression style of Bra 2. Biomechanical asymmetry has been reported to be individual to participants during running gait (Exell et al., 2017; Exell, Irwin et al., 2010); therefore, it is likely that individual asymmetry profiles exist relating to dynamic breast movement. The individual responses of participants to different bras demonstrated in Collection B, along with the fact that asymmetry was still present in all support conditions highlights the need for further work to allow for customised breast support for each breast. This development may be achieved by adding greater adjustability to each strap by way of different elastic properties or by adding adjustability to the individual cups of sports bras.

From a data collection perspective, the high number of participants demonstrating asymmetry of breast movement in at least one direction highlights the importance of collecting bilateral data when investigating breast movement. Collection of unilateral data is not recommended as it could change the conclusions being drawn from research studies (Exell, Gittoes et al., 2012). Furthermore, it is not recommended that data are averaged from left and right sides as asymmetry that is present may be functional or compensatory and averaging across sides may lead to 'mythical average' data that does not truly represent either side of the body.

Further research in this area should consider the influence of dynamic breast asymmetry on asymmetry of other variables such as step characteristics during gait (Exell et al., 2017) and other upper-body kinematics (White et al., 2015) to establish whether relationships exist between asymmetry of breast movement and other performance variables. In addition, it would be useful to quantify asymmetry differences related to aging, to establish whether changes in the mechanical properties of the supporting skin structure during aging increases asymmetry prevalence (Luebberding, Krueger & Kerscher, 2014). When considering the practical applications and differing breast support requirements between sides, it is suggested that manufacturers consider how bras can be developed to allow more customisable support between sides, such as by adding size or tension control to each cup independently and customising the elastic properties of each strap.

Conclusion

The prevalence of breast movement asymmetry was high with 149 of the 167 women tested showing significant asymmetry. The asymmetry reported was most often due to greater movement of the left than right breast. Breast movement asymmetry was not related to overall breast size, indicating that it may be present in participants of all breast sizes. Use of a sports bra reduced the occurrence and magnitude of asymmetry, depending on the bra, but did not eliminate it. In poorer performing sports bras, the larger movement experienced by one breast may lead to pain in that breast when wearing a bra for exercise. The most effective sports bra for reducing asymmetry allowed for adjustment of both the shoulder straps and underband.

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Table 1. Number of participants that displayed significant asymmetry, whether left or right ROM was larger for asymmetrical participants and mean cross grade size for significantly asymmetrical and non-asymmetrical participants during dynamic trials. Directions relate to the thorax coordinate system: AP = antero-posterior, ML = medio-lateral, IS = infero-superior, RT = resultant.

	Direction			
	AP	ML	IS	RT
Number of participants showing significant asymmetry (% or total)	84 (50%)	83 (50%)	106 (63%)	86 (51%)
Number of participants with L>R ROM, of those showing significant asymmetry (% or asymmetrical participants)	63 (75%)	51 (61%)	64 (60%)	56 (65%)
Mean cross grade size (significant asymmetry)	5.49	5.64	5.55	5.46
Mean cross grade size (non-significant asymmetry)	5.55	5.40	5.47	5.58

Table 2. Comparisons of static asymmetry magnitude for participants that displayed significant asymmetry during running trials and those that did not. Directions relate to the thorax coordinate system: AP = antero-posterior, ML = medio-lateral, IS = infero-superior, RT = resultant. ES = effect size.

	Direction							
	AP		ML		IS		RT	
	A	NA	A	NA	A	NA	A	NA
Mean (±SD)	6.52 (6.00)	5.66 (4.15)	3.48 (2.88)	2.98 (2.48)	1.34 (1.27)	1.45 (0.96)	1.32 (1.05)	0.89 (0.66)
sig	0.40		0.35		0.64		0.04*	
ES	0.17 [T]		0.19 [T]		0.10 [T]		0.50 [S]	

* = significant difference between static asymmetry magnitude for asymmetrical (A) and non-asymmetrical (NA) groups during dynamic running. [T] = trivial, [S] = small effect sizes.

Table 3. Spearman (ρ) correlations between asymmetry magnitude and bra size / pain score for participants displaying significant asymmetry in each direction during dynamic trials (values in brackets are associated p-values). Directions relate to the thorax coordinate system: AP = antero-posterior, ML = medio-lateral, IS = infero-superior, RT = resultant.

	Direction			
	AP	ML	IS	RT
Size	0.06	-0.12	0.06	-0.01
p	(0.62)	(0.27)	(0.57)	(0.89)
Pain	0.03	0.02	0.12	0.18
p	(0.81)	(0.86)	(0.27)	(0.14)

Table 4. Number of participants from sub-group of twelve, displaying significant asymmetry in each direction during different bra conditions (values in brackets are associated percentages). Directions relate to the thorax coordinate system: AP = antero-posterior, ML = medio-lateral, IS = infero-superior, RT = resultant.

	Direction			
	AP	ML	IS	RT
No Bra	9 (75%)	10 (83%)	9 (75%)	9 (75%)
Bra 1	4 (33%)	7 (58%)	8 (67%)	7 (58%)
Bra 2	9 (75%)	8 (67%)	9 (75%)	11 (92%)
Bra 3	6 (50%)	10 (83%)	8 (67%)	7 (58%)

Table 5. Magnitude of largest range of motion asymmetry (mm) across all sub-group participants in each direction during all bra conditions. Directions relate to the thorax coordinate system: AP = antero-posterior, ML = medio-lateral, IS = infero-superior, RT = resultant.

		Direction			
		AP	ML	IS	RT
No Bra	Mean	8	11	14	19
	(sd)	6	11	20	24
	Max	22	38	67	80
Bra 1	Mean	3	1	3	3
	(sd)	2	0	2	1
	Max	6	1	6	5
Bra 2	Mean	4	3	7	6
	(sd)	2	1	6	6
	Max	9	5	22	21
Bra 3	Mean	6	4	10	12
	(sd)	6	8	22	26
	Max	18	25	64	71