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BREAST MOTION ASYMMETRY DURING RUNNING

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Abstract

Breast asymmetry is common in females, therefore, despite a similar driving force; dynamic activity may result in asymmetrical breast motion. This preliminary study investigated how breast categorisation (left/right or dominant/non-dominant) may affect breast support recommendations and relationships to breast pain. Ten females ran on a treadmill at 10 kph in three breast supports (no bra, everyday bra, sports bra). Five reflective markers on the thorax and nipples were tracked using infrared cameras (200 Hz) during five running gait cycles in each breast support. Multiplanar displacements of both breasts were calculated relative to the thorax. Although the maximum individual participant difference was 2.4 cm (mediolaterally) between the left and right breast, no left/right differences were found in any direction or support condition. Notably, correlations between breast pain and anterioposterior breast displacement decreased from a strong relationship with the left breast ($r=0.614$) to a moderate relationship with the right breast ($r=0.456$). Following participant categorisation according to the greatest magnitude of superioinferior breast displacement (dominant breast), results showed significant differences in displacement for all directions across different breast supports. When using breast kinematic data to examine relationships to breast pain or to recommend breast support requirements, data on both breasts should be collected.

Keywords: displacement; bra; exercise; kinematics

1. Introduction

Females vary considerably in terms of the size, contour and density of their breasts at maturity (Hoffmann, 2001). Breast asymmetry has been reported in 62% (Losken, Fishman, Denson, Moyer & Carlson, 2005) and 82% (Gabriel et al. 2011) of the population, with the left breast often being larger than the right (Losken et al. 2005; Page & Steele, 1999). It has been reported that the mass of a non-lactating breast ranges from 150 to 225 g (Macea & Fregnani, 2006) and differences in breast sizes are usually attributed to variations in adipose tissue which may be representative of different breast masses (Page & Steele, 1999). The mass of the breast has also been shown to be related to the suprasternal notch to nipple distance, with increases in breast mass being associated with inferior migration of the nipple during static conditions (Brown et al., 2012). During dynamic movements the motion of the soft tissue of the breast is governed by the driving force of the trunk (Haake & Scurr, 2010), the viscoelastic properties of the breast tissue (Gefen & Dilmoney, 2007), and any external breast support garment being worn (Singha, 2012; Zhou, Yu & Ng, 2012a). During physical activities such as running breast mass asymmetry may result in different kinematics for each breast based on the same driving force of the trunk. A single breast (left; Zhou, Yu & Ng, 2012b), (right; Bridgman, Scurr, White, Hedger & Galbraith, 2010; Scurr, White & Hedger, 2010; White, Scurr & Smith, 2009) is commonly used to make recommendations on improvements to breast support design (Zhou et al., 2012a) and to investigate the effect of breast support levels on breast kinematics and exercise induced breast pain (Bridgeman et al., 2010; Scurr et al., 2010; White et al., 2009).

Multiplanar breast kinematics research during running has identified that the greatest magnitude of breast displacement occurs superioinferiorly (Scurr, White & Hedger, 2009; Scurr et al., 2011) and that sports bra design should aim to predominantly reduce breast displacement in this direction (Scurr et al., 2011). However, these recommendations are based on the analysis of breast kinematics from only one breast. A further consideration is that the symmetrical design and manufacture of a bra (Hardaker & Fozzard, 1997) means that any breast asymmetry may reduce the effectiveness of the support of the bra for the smaller breast, since bra fit recommendations suggest the bra should be fitted to the larger breast (Figleaves, 2007).

An increase in superioinferior breast displacement has also been positively correlated with increases in exercise induced breast pain (Bridgeman et al., 2010; Scurr et al. 2010) and consequently breast biomechanics research has made recommendations to wear a high level of breast support (sports bra) when exercising to reduce breast pain (Bridgman et al., 2010; Scurr et al., 2010; White et al., 2009). Due to potential differences in bilateral breast mass due to asymmetry, the strength of correlations between breast kinematics and breast pain and subsequent recommendations for bra design may depend upon the researcher’s decision to analyse the left or right breast. One previous study investigated the difference in resultant breast displacement between the left and right breast during treadmill running and found no significant differences (Scurr, White and Hedger, 2011). However, as differences in breast size and mass may occur in either breast, it may be possible that the greatest breast motion occurs in the left breast for some individuals and in the right for others, resulting in no difference in displacement between the breasts as reported by Scurr et al. (2011). If this is the case, different bra designs and support recommendations may be required to further reduce levels of breast displacement and pain for asymmetrical breasts.

In other areas of biomechanics the majority of research involving the execution of a skill with a single limb has focussed on the dominant or preferred kicking (Anderson & Dorge, 2011) or throwing limb (Forestier & Nougier, 1998). Limb movement asymmetry has been investigated in various sporting activities, such as football kicking (Barfield, Kirkendall &Yu, 2002; Dorge, Bullanderson, Sorensen, Simonsen, 2002) and cricket throwing (Sachlikidis & Salter, 2007). Limb asymmetry research often categorises the participant's dominant or preferred limb, rather than the left and right (Anderson & Dorge, 2011). It may be possible to re-categorise the breast in a similar way using the magnitude of breast displacement, hence demonstrating a possible difference in displacement and consequently the support requirements between breasts. Therefore, it may be more appropriate to analyse the motion of both breasts and report the side exhibiting the most superioinferior displacement (categorised as the dominant breast) as the selection for subsequent correlations to breast pain.

Segment mass can affect movement performance (Werner, Suri, Guido, Meister & Jones, 2008), thus if breast asymmetry exists, the breast with a greater mass, moving due to the same driving force, will have different kinematics. Investigating differences in multiplanar breast displacement between the left and right, dominant and non-dominant breast may help to inform experimental design, have implications for breast support requirements and provide a further understanding of the relationship between breast displacement and exercise induced breast pain. The aim of this study was to quantify bilateral breast displacement in three breast support conditions during treadmill running and subsequently investigate how the selection of one breast over the other may affect breast support requirements and the relationship to exercise induced breast pain. It was firstly hypothesised that there will be no significant difference between multiplanar left and right breast displacements. Secondly, there will be a significant difference in multiplanar dominant and non-dominant breast displacements, with greater breast displacements being associated with the dominant breast. Thirdly, the relationship between breast displacement and exercise induced breast pain will differ depending upon breast categorisation.

2. Methods

Following institutional ethical approval, ten female participants (mean ± *SD*: age 22 ± 2 years, height 1.65 ± .04 m, body mass 61.0 ± 2.4 kg) gave written informed consent to take part in the study. Participants were selected if they were recreationally active, aged between 18 and 39 years, were not pregnant, had no history of breast surgery, had not given birth or breast-fed in the last year, and were a 32D cup size. The 32D cup size was selected for comparison with previous research and due to exercise related breast pain being more prevalent in women of a D cup size or above (Lorentzen & Lawson, 1987; White et al., 2009). Participant's bra breast size was measured by a trained bra fitter following best fit recommendations (White & Scurr, 2012).

Participants completed a self-directed treadmill warm up (H/P/Cosmos Mercury, Germany). Following the warm up, retroreflective passive markers (.005 m radius) were positioned on the suprasternal notch, left and right anterior inferior aspect of the 10th ribs, and on the left and right nipples (Scurr et al., 2011). A nipple marker has previously been shown to give a reliable and valid measure of gross breast displacement (Mason, Page & Fallon, 1999). An additional heel marker was added to track gait cycles (Scurr et al., 2010). Three dimensional movement of the markers were tracked using eleven optoelectronic cameras sampling at 200 Hz (Oqus, Qualisys, Sweden), positioned in an arc around the treadmill. Cameras were calibrated using a coordinate frame positioned on the treadmill and a handheld wand containing markers of predefined distances (QTM [Qualisys Track Manager]; version 1.10.828, Qualisys, Sweden).

Participants ran at 10 kph for a two minute familiarisation period, after which marker coordinates were recorded for five gait cycles (Scurr, White & Hedger, 2010; 2011) in three breast support conditions (no bra, everyday bra and sports bra). The everyday bra was a Marks and Spencer Seamfree Plain non-padded Under wired T-Shirt Bra (made from 78% polyamide and 22% elastane lycra), and the sports bra was the UK leading branded sports bra manufacturers best-selling encapsulation sports bra (Shock Absorber Run bra, made from 81% polyamide, 10% polyester, 9% elastane). After each trial, participants rated their overall exercise induced breast pain using a numerical scale for breast pain, this scale defines 0 as “no pain”, and 10 “painful” (Mason, Page & Fallon, 1999).

Markers were identified and reconstructed in QTM, and a fast Fourier transformation was performed on the reconstructed data in MatLab (version R2010a). The power spectrum revealed that approximately 85% of the signal power was below 16 Hz and a subsequent residual analysis, based on Winter (2009), determined a cut-off frequency of 13 Hz. The data were subsequently filtered using a second order low pass Butterworth filter with a cut off of 13 Hz and exported into a transformation matrix (Foley et al., 1995). This matrix transformed the global coordinate system into a local orthogonal coordinate system using a direct frame by frame method (Scurr et al., 2010), identifying the suprasternal notch as the origin and establishing the right and left nipple coordinates relative to the trunk (Scurr et al., 2010). The right and left ribs were used to calculate a virtual mid-rib point. The normalised vector extending from the mid-rib point to the suprasternal notch defined the longitudinal axis (superioinferior axis). The suprasternal notch marker was then used to construct two vectors within the trunk reference plane (vector 1 extending from the suprasternal notch to the left rib, and vector 2 extending from the right rib to the suprasternal notch). The normalised cross product between vectors 1 and 2 defined the second axis (anterioposterior). A right handed local co-ordinate system for the trunk defined the mediolateral axis (Mills et al., 2014).

Gait cycles were determined using the change in foot marker velocity along the anterioposterior axis, and the instant at which the velocity vector of this marker changed from positive to negative indicated heel strike for each gait cycle (Zeni, Richards & Higginson, 2008). Left and right breast displacement relative to the trunk was subsequently calculated as the maximum minus the minimum position of each nipple within one gait cycle. The data of five running gait cycles were averaged and superioinferior, mediolateral and anterioposterior displacement was reported in metres (m) (Scurr et al. 2010). Dominant and non-dominant breast categorisation was implemented by examining the magnitude of superioinferior breast displacement (the direction in which the greatest breast displacement occurred; Scurr et al. 2010) of each breast, within each participant, and assigning the breast with the greatest superioinferior displacement as the dominant breast and the least as the non-dominant breast.

All data were checked for normality using the Shapiro-Wilks tests, paired samples T-tests or Wilcoxon Signed rank tests were used to assess any differences between left and right breast displacement (or dominant and non-dominant) within each breast support condition. All data were parametric ($p>0.05$) and were assessed using T-tests, except superioinferior breast displacement in the everyday bra condition which was assessed using the Wilcoxon Signed rank test. Effect sizes using Cohen's *d* (or *r* for non-parametric) are reported for significant results to provide an indication of the magnitude of the observed effect. A large effect size was defined as $d > 0.8$, moderate as between 0.8 and 0.5, and a small effect size defined as < 0.5 (Field, 2013). Spearman's rho correlations assessed relationships between breast displacement and exercise induced breast pain. Correlation coefficients (r) of 0.1 to 0.29 defined a small relationship, 0.3 to 0.49 a moderate relationship and 0.5 to 1 a strong relationship (Field, 2013).

3. Results

Seventy percent of participants had greater superioinferior displacement of the left breast during no bra running (Figure 1), 90 % in the everyday bra (Figure 2), 60 % in the sports bra (Figure 3). The greatest individual participant difference was 1.6 cm (superioinferiorly) between the left and right breast displacements in the no bra condition (Figure 1), however, no significant differences (p>0.05) were found between the left and right breasts in any direction or breast support condition (Figures 2 and 3).

**** Insert figure 1 here ****

**** Insert figure 2 here ****

**** Insert figure 3 here ****

Interestingly, the direction in which the greatest left breast displacement occurred was mediolaterally in both the no bra (0.064 m) and sports bra condition (0.030 m), and anterioposteriorly in the everyday day (0.042 m). However, this was different for the right breast, with the greatest displacement occurring in the mediolateral direction in the no bra (0.059 m) and everyday bra (0.041 m) condition and in the anterioposterior direction in the sports bra condition (0.031 m).

Following breast displacement categorisation into dominant and non-dominant breast, significantly greater breast displacement in dominant breast was found in the anterioposterior direction (t=2.390, p=0.041; d = 0.52), mediolateral direction (t=2.479, p=0.035; d = 0.35) and the superioinferior direction (t=6.445, p=0.000; d = 0.31) compared to the non-dominant breast in no bra running. Significantly greater dominant breast displacements were also found in the anterioposterior direction (t=3.397, p=0.008; d = 0.47) and superioinferior direction (Z=2.823, p=0.005; r = 0.89) in the everyday bra condition and in the superioinferior direction (t=3.597, p=0.006; d = 0.33) in the sports bra condition (Figure 4).

****Insert figure 4 here ****

During running exercise induced breast pain was rated as 6.0 out of 10 in the no bra condition, 4.4 in the everyday bra and 0.5 in the sports bra. The correlation coefficient between breast pain and displacement differed for the left and right breast. For example, breast pain showed a strong relationship (r=0.614) to anterioposterior displacement of the left breast, but only a moderate relationship to the right breast (r=0.456). Interestingly, the strength of the relationship did not differ between the dominant and non-dominant breast (Table 1).

****Insert Table 1 here ****

4. Discussion

The effect of any possible breast asymmetry on breast kinematics for the same trunk driving force was unknown; therefore this preliminary study aimed to quantify the displacement of both breasts during running and subsequently investigate how the breast categorisation (left or right and dominant or non-dominant) may affect breast support requirements and the relationship to exercise induced breast pain. Key findings have shown that there are no significant differences in breast displacement between the left and right breast within any of the three breast support conditions, accepting hypothesis one. However, maximum individual differences were up to 1.6 cm in the superioinferior direction, with 70 % of the female participants having greater superioinferior displacement of the left breast in the no bra condition, 90 % in the everyday bra and 60 % in the sports bra compared to the right breast. This suggests that individual differences within the sample group may have off set each other when comparing the sample group mean.

Categorising breast displacement by the dominant (greatest displacement) and non-dominant (least displacement) breast, based upon individual maximum superioinferior breast displacement (the direction in which greatest breast motion occurs; Scurr et al., 2009; 2011), revealed significant differences between dominant and non-dominant breast displacements in all directions in the no bra condition. Significant differences were also found in the anterioposterior direction and superioinferior direction in the everyday bra and in the superioinferior direction in the sports bra condition, accepting hypothesis two. This suggests breast movement asymmetry does occur which may be linked with the reported differences in breast size and density (Losken et al. 2005; Page & Steele, 1999), and hence mass, since breast mass and individual breast size and density are difficult to measure directly (Page & Steele, 1999). Other studies have also shown that mass can affect movement performance (Werner et al., 2008) in which a leg or arm with a greater mass moving due to the same driving force has a difference in kinematics. The reported differences in kinematics between the breasts suggest different breast support requirements exist for each breast. These results have significant implications for bra design recommendations, advice on minimising exercise induced breast pain as well as breast biomechanics research protocols.

Asymmetrical breast kinematics will have implications on bra design recommendations since the direction in which the greatest breast displacement occurred differed depending upon left or right breast selection. If this preliminary study had collected breast displacement data from the left breast only, the conclusion would have been to minimise anterioposterior breast displacement in everyday bras, alternatively if this study had only collected data from the right breast it would have concluded that mediolateral breast displacement reduction was necessary. Therefore, this study highlights that future breast biomechanics research should collect data from both breasts before making bra design recommendations. Furthermore, the results raise the issue as to whether bra manufacturers could develop asymmetrical cups or customisable bra cups to minimise the displacement of each breast individually. This also raises a further challenge regarding how consumers determine significant breast asymmetry that may require asymmetrical cup design and how manufacturers can practically produce bras with asymmetrical cups that can cater for all combinations and magnitudes of breast asymmetry. This approach may need to begin with a case study of participants prior to possible breast asymmetry corrective surgical intervention (Neto et al. 2007).

A further key finding of this study showed that the correlation coefficient between exercise induced breast pain and breast displacement decreased from a strong relationship in anterioposterior displacement for the left breast (r=0.614) to a moderate relationship for the right breast (r=0.456), partially accepting hypothesis three for this measure. Furthermore, if the left breast were selected for this study, correlation coefficients suggest breast pain has the strongest relationship with anterioposterior displacement, then superioinferior and finally mediolateral breast displacement. However, if the right breast were selected instead, breast pain would demonstrate the strongest relationship with mediolateral, followed by superioinferior, then anterioposterior breast displacement. These findings have implications on the recommendations made to bra manufacturers regarding design features (Zhou et al. 2012a) aimed at reducing breast pain via a reduction in multiplanar breast displacements. The categorising of the breasts to dominant and non-dominant showed that breast pain had the strongest relationship with superioinferior breast displacement, followed by mediolateral displacement and finally anterioposterior displacement. These consistent findings using the dominant and non-dominant breast reinforce this categorisation approach. In future breast biomechanics research it is recommended that data on both breasts are collected before making recommendations regarding reducing breast pain as data collected on one breast may not be representative of the other due to movement asymmetry. One note of caution relates to the marker set used in this study, it is likely that the distal ribs markers are close to substantial amounts of subcutaneous fat. Future research that aims to investigate breast kinematics and breast pain may need to investigate the use of a different marker set (for example, a modified International Society of Biomechanics thorax marker set, Wu et al., 2005) that reduces possible soft tissue artefact associated with the rib markers in this study, whilst not being obscured by the breast support garments worn by the participants.

It is interesting to note that during this study the direction in which the greatest breast displacement occurred changed depending upon breast support level and the left or right breast. This is in contrast to the majority of published research that has reported that the greatest breast displacement occurs in the superioinferior direction (Bridgeman et al., 2010; Scurr et al., 2010; White et al., 2009). White et al. (2009) found 50% of breast displacement occurred in the superioinferior direction, 25% in the both the mediolateral and anterioposterior directions within a no bra condition. As support level increased this changed to 44% in the superioinferior direction, 28% in the both the mediolateral and anterioposterior directions within a sports bra condition. Despite the increase in breast support the greatest breast displacement remained in the superioinferior direction for the right breast. The present study found that the greatest breast displacement occurred in a different direction depending upon breast support level and the breast used for analysis (left or right). For example, the greatest left breast displacement occurred in the mediolateral direction for the sports bra condition, but this changed to the anterioposterior direction for the right breast. This conflict in findings also has implications on bra design recommendations such as the direction in which bra design should minimise breast displacement, which could depend upon the selection of either the right or left breast, and reinforces the need for a robust methodology for the categorisation and calculation of breast biomechanical data. Furthermore, this study has demonstrated that regardless of breast asymmetry and without the need to measure it directly, it is still possible to identify an effect and a categorisation method to deal with it.

5. Conclusion

The results of this preliminary study suggest that when using breast kinematic data to understand breast support requirements, provide recommendations on bra design and to examine relationships with breast pain it is advised that data are collected from both breasts. The researchers can subsequently check for any movement asymmetry by categorising the breasts as dominant or non-dominant then decide whether to present data on both breasts or just the dominant one if movement asymmetry is present. Furthermore, the selection of either the left or right breast may be misleading in terms of recommendations regarding bra design.

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Table 1. The correlation between self reported breast pain and breast displacement during running for each participant (n=10) across all breast support conditions.

	Spearman's correlation coefficient (r)	P-value
Anterioposterior		
Left breast displacement	0.614	0.000
Right breast displacement	0.456	0.011
Dominant breast displacement	0.500	0.005
Non-dominant breast displacement	0.562	0.001
Mediolateral		
Left breast displacement	0.503	0.005
Right breast displacement	0.661	0.000
Dominant breast displacement	0.576	0.001
Non-dominant breast displacement	0.563	0.001
Superioinferior		
Left breast displacement	0.600	0.000
Right breast displacement	0.596	0.001
Dominant breast displacement	0.605	0.000
Non-dominant breast displacement	0.598	0.000

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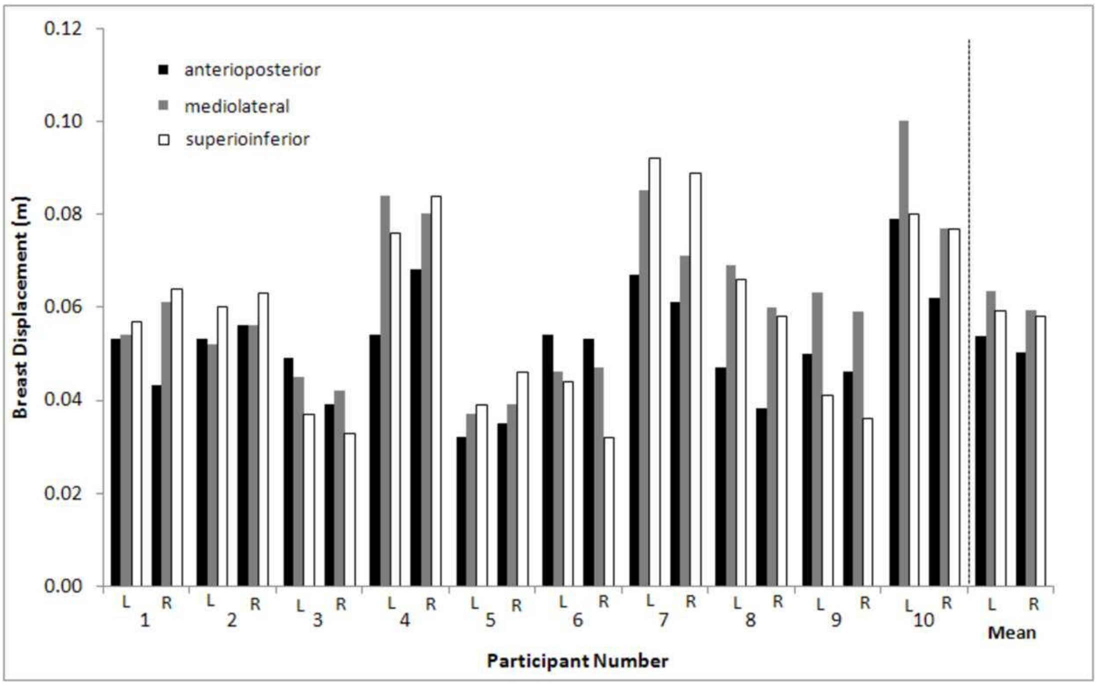

Figure 1. Multiplanar breast displacement in the no bra condition during treadmill running at 10 kph (L = left breast, R = right breast).

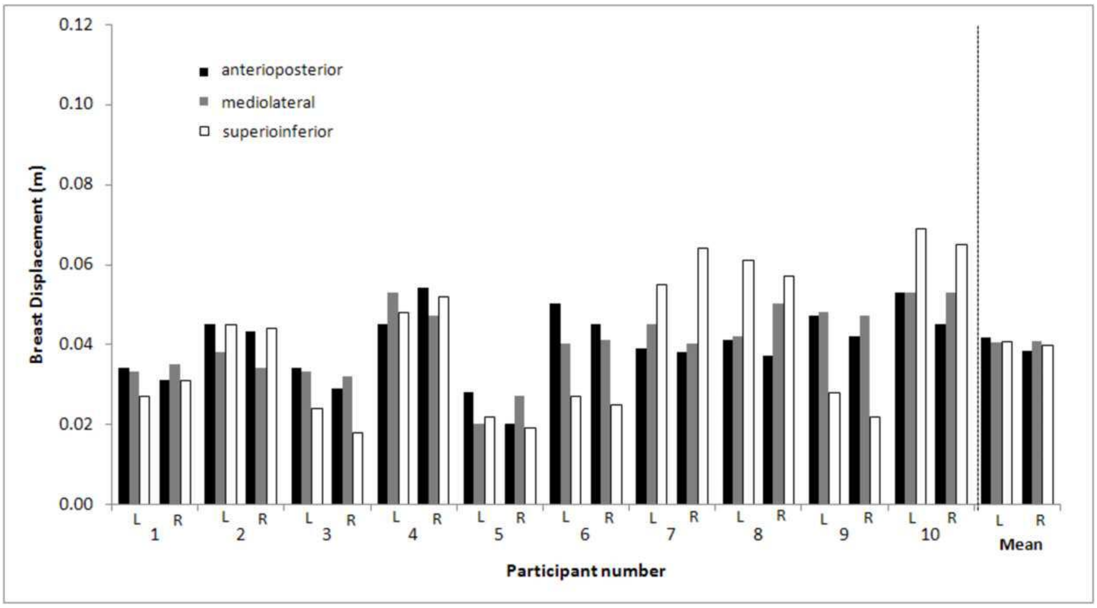

Figure 2. Multiplanar breast displacement in the everyday bra condition during treadmill running at 10 kph (L = left breast, R = right breast).

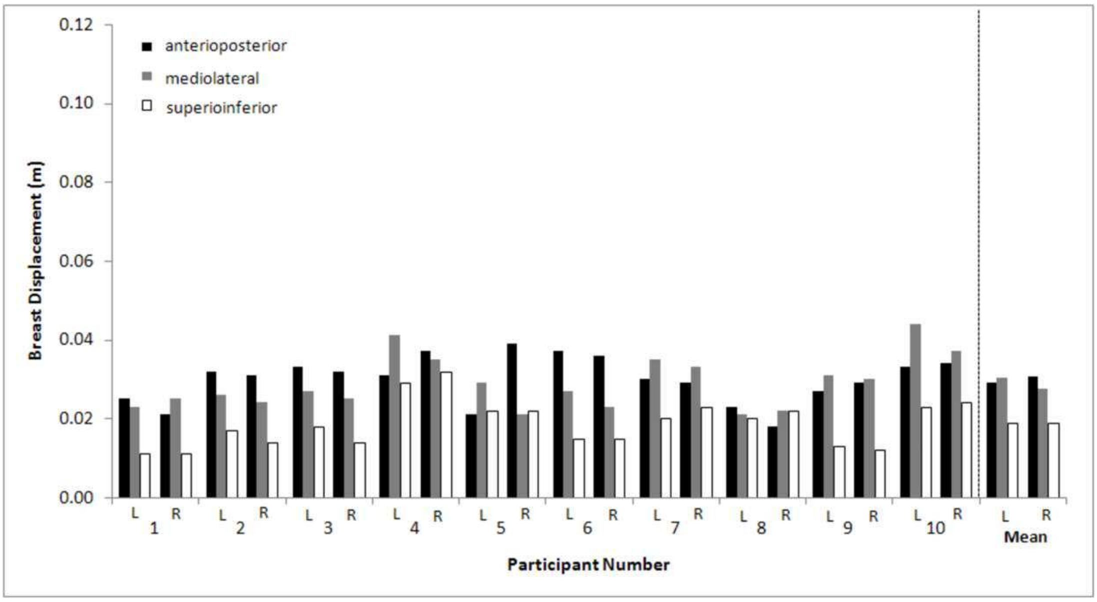

Figure 3. Multiplanar breast displacement in the sports bra condition during treadmill running at 10 kph (L = left breast, R = right breast).

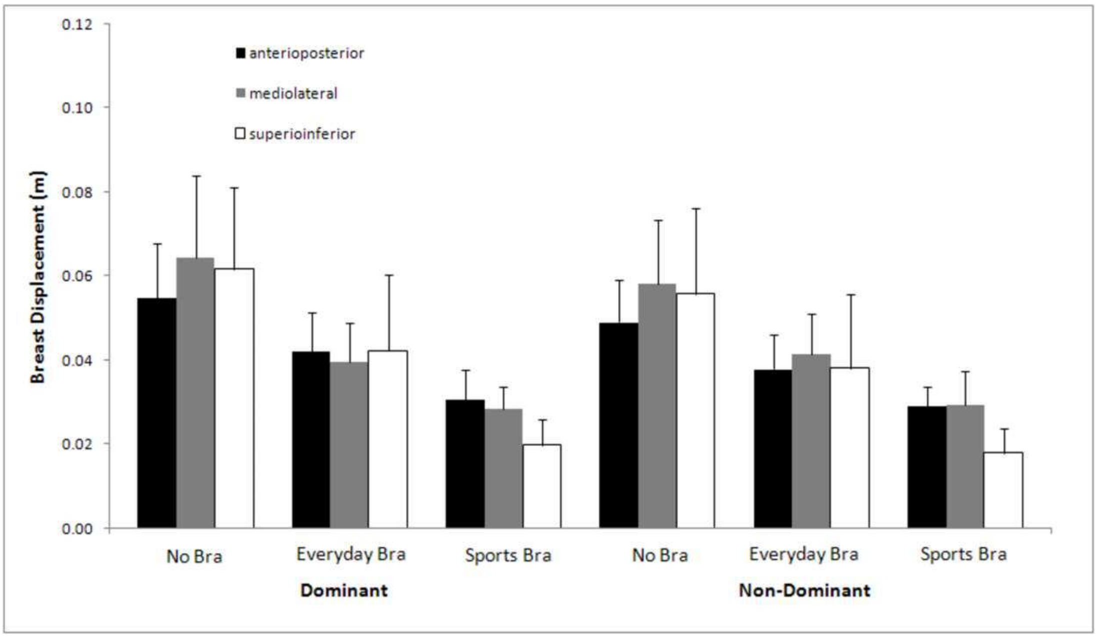

Figure 4. Mean (standard deviation) multiplanar breast displacement of the dominant and non-dominant breast during treadmill running at 10 kph in three breast support conditions (n = 10).