

**The effectiveness of a range of sports bras in reducing breast displacement  
during treadmill running and two-step star jumping**

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## **Abstract**

*Aim.* The primary aim of the study was to investigate the effectiveness of a range of sports bras in reducing multi-planar breast displacement during treadmill running and a two-step star jump. A secondary aim was to assess the relationship between perceptual bra comfort, bra fit and breast pain and measured breast displacement.

*Methods.* Seventeen females (mean age 22 years, range 18 – 31 years) with bra cup sizes B to C volunteered to take part in the study. Three dimensional breast movements were determined for six randomly assigned breast support levels during treadmill running and two-step star jumping. Participants completed a perceptual questionnaire rating bra comfort, bra fit and breast pain.

*Results.* Not all the bras significantly reduced resultant breast movement compared to a control condition. Not all the bras reduced resultant breast movement significantly at all

speeds during the treadmill test. A different bra performed best during each of the treadmill running speeds. Perceptual ratings of bra fit and bra comfort were stronger and more reliable predictors of breast pain than breast displacement in our group of relatively small breasted participants. *Conclusion.* Therefore it is apparent that resultant breast movement and the reduction of such movement is a multifaceted function of breast size, bra design and movement/activity type. The variance in bra performance at different treadmill running speeds highlights this fact and indicates that sports bras should be carefully selected to best suit the activity and breast size of the user.

**KEYWORDS:** breast movement – kinematics - sports bra – exercise.

## **Introduction**

Experts within the health and fitness industry have suggested that active females should wear a well-fitting sports bra in order to reduce pain and motion of the breasts during exercise.<sup>1</sup> It has been found that up to 75% of females do not wear the appropriate sportswear and are unaware of how to correctly choose a sports bra.<sup>1</sup> A significant percentage of woman experience sports related breast pain and/or discomfort, and the most common cause of this pain is related to excessive breast motion.<sup>2</sup>

Currently there are two sports bra designs dominating the market. The encapsulating bra for bigger busted women with a cup size C to D who require more support; and the compression bra for smaller busted women with a cup size A to B.<sup>2,3</sup> Most sports bras are anchored to the body by strong elastic or under wire beneath the breast.<sup>2</sup> Additional design features of sports bras may include a higher neckline anchored with strong elastic to limit upward motion of the breast. However, no matter how successful the design of the bra,

incorrect fit and/or size will result in insufficient support and render the garment ineffective.<sup>2,4</sup> The inability to find a suitably supportive bra could lead to breast discomfort and non-participation in sport with poor adherence to exercise.<sup>3-5</sup>

Although great effort has been made in understanding the association between vertical breast displacement and velocity with breast pain, the influence of breast comfort and kinematics has yet to be fully understood.<sup>6</sup> Furthermore, it is important to understand that breast motion is not only a vertical movement but is three-dimensional. This is best described as motion within six degrees of freedom: namely the ability of the breast to move in three directions anteriorly/posteriorly, superiorly/inferiorly, medially and laterally.<sup>6-8</sup> Thus awareness of how different modes of exercise and activity and different types and levels of breast support impacts breast motion, breast discomfort, risk of injury to breast tissue and exercise performance is important for all exercising women.<sup>3,5,9</sup>

Therefore, the primary aim of the study was to investigate the effectiveness of a range of sports bras in reducing multi-planar breast displacement during treadmill running and performance of a two-step star jump. It was hypothesised that the bras with a higher level of support [High (H) and High Impact Ultimate (HIU)] would result in significantly less overall breast displacement at all speeds of a treadmill test and during two-step star jumping in comparison to the participants' own (O) choice of bra and a no-bra control (C) condition. A secondary aim was to assess the relationship between perceptual bra comfort, bra fit and breast pain and measured breast displacement. It was hypothesised that there would be: strong relationships between perceptual ratings of bra fit and bra comfort; strong inverse relationships between perceptual ratings of bra fit and comfort and ratings of breast pain; and strong relationships between breast displacement and perceptual ratings of breast pain.

## **Materials and methods**

### *Study participants*

Ethical approval for the study was obtained from the Postgraduate and Ethics Committee of the Faculty of Humanities, University of Pretoria, South Africa. Seventeen females with no history of breast surgery or pregnancy, and bra cup size B to C (bra sizes that were available from the manufacturer) were recruited for the study. The participants had the following mean ( $\pm$  SD) characteristics: age  $22.4 \pm 2.9$  years, body mass  $59.4 \pm 8.1$  kg and stature  $164.1 \pm 7.1$  cm. Participants were required to be familiar with treadmill running and participate in at least 30 minutes of exercise twice per week. Participation was voluntary and all participants completed and signed informed consent prior to initiation of the study. Participants were recruited by means of advertisements placed around the University campus and interested participants had to complete a questionnaire and be assessed for bra size to determine eligibility.

### *Data collection*

Participants were assessed on three separate occasions with one day rest between each assessment. During the first session stature (cm) and body mass (kg) were measured and recorded by a qualified anthropometrist (International Society for the Advancement of Kinanthropometry – ISAK). Breast size was assessed to determine bra cup size according to the methods of McGhee and Steele.<sup>10</sup> During the second and third sessions, three dimensional breast movements were determined for six randomly assigned breast support levels (three per day) during treadmill running and performance of a two-step star jump. A commercially available sports bra range was used to provide four varying levels of breast support. Breast movement under these four support conditions were compared to a control condition (no bra) as well as the personal choice of bra by each participant. While the fit and design of

participants' own bras were not standardised, the condition was included in order to provide the participants with feedback on the effectiveness of their own choice of bra worn during exercise. In summary, the breast support conditions included: Control (C) (no bra), participant's own bra (O), low support (L), medium support (M), H and HIU support level bras. The M, H and HIU bras were of an encapsulating design while the L support level bra was of a compression design. Upon completion of each trial (treadmill test and the two-step star jumps) participants were asked to rate bra comfort, bra fit and breast pain by completing a perceptual questionnaire, based on a visual analogue scale. Participants had to rate bra comfort (0 being very uncomfortable and 10 being very comfortable); bra fit (0 being very poor fit and 10 being very good fit) and breast pain (0 being no pain and 10 being excruciating pain).<sup>14</sup>

The Qualisys Motion Capture Analysis hardware (sampling frequency set at 250 Hz) and software (QTM) (Qualisys, Sweden) was used to capture three dimensional breast movements. Retro-reflective markers were placed on the right nipple, suprasternal notch, and the anteroinferior aspects of the 10<sup>th</sup> ribs. During the bra conditions markers were repositioned on the bra over the nipple.<sup>11</sup> Trunk markers were used to establish relative breast kinematics, independent of the six degrees-of-freedom movement of the trunk according to the methods described by Scurr and colleagues.<sup>11</sup> The suprasternal notch was used as the origin of the local coordinate system from which nipple translation was calculated.

The treadmill test started with a two minute familiarization period at 4 km/h, thereafter speed was increased by 2 km/h every 2 minutes until the participant reached 10 km/h. Breast movement was calculated based on the recorded marker positions and averaged for 5 strides, as determined from heel strike to heel strike, using a reference marker placed on the right calcaneus. Relative superoinferior, mediolateral, and anteroposterior nipple coordinates during the five gait cycles were filtered using a 10-Hz low-pass Butterworth filter.<sup>11</sup> After

completion of the treadmill protocol participants rested for two minutes after which, they performed five repetitions of the two-step star jump during which breast displacement was recorded. Research suggests that performing a two-step star jump is a valuable test to analyse breast displacement, as it is a dynamic whole body movement.<sup>12</sup> This test requires motor coordination between upper and lower-body segments and includes both horizontal and vertical movements.<sup>13</sup> The two-step star jump consists of two phases. The first phase is initiated with the participant's feet shoulder width apart, followed by a lateral jump, abducting both the arms and the legs until ground contact. Phase two comprises of the participant jumping medially, adducting both the legs, returning to the starting position.<sup>13</sup> The treadmill test was then repeated, randomised for all support conditions after participants had adequately recovered.

#### *Data analyses*

Descriptive statistics were used to calculate the minimum, maximum and mean displacement in millimetres (mm) of the breast while walking and running on the treadmill at 4 km/h, 6 km/h, 8 km/h, and 10 km/h and while performing the two-step star jump. After tests for normality of the data, non-parametric comparisons (Friedman test) of breast displacement in three planes of motion as well as resultant displacement were determined across support conditions and compared to the C condition. Statistically significant results were followed by post-hoc pairwise comparisons using Wilcoxon Signed Ranks tests. Statistical significance was predetermined at a p-value of equal to or less than 0.05 ( $p \leq 0.05$ ). Spearman's rho correlation coefficients were calculated to quantify the relationship between resultant breast displacement and perceptual ratings of bra comfort, bra fit and breast pain ratings across breast support conditions rated at the end of each treadmill test, with values of 0.10 to 0.29 defining a weak relationship, 0.30 to 0.49 a moderate relationship and 0.50 to 1 a

strong relationship.<sup>15</sup> The data was statistically analysed by means of IBM SPSS Statistics version 19.

## Results

Seventeen females with bra cup sizes B to C volunteered to take part in the study. The participants had the following mean ( $\pm$  SD) characteristics: age  $22.4 \pm 2.9$  years, body mass  $59.4 \pm 8.1$  kg and stature  $164.1 \pm 7.1$  cm. Table 1 presents the multi-planar displacement (mm) of the breast, relative to the movement of the trunk at various speeds on the treadmill as well as during the performance of the two-step star jump. Resultant breast displacement increased correspondingly with treadmill speed across all support conditions. There were no significant differences ( $p > 0.05$ ) for resultant breast displacement between the C and other support conditions at 4 km/h during the treadmill test. All support conditions were effective in limiting resultant breast movement significantly ( $p < 0.05$ ) when compared to the control condition at 6 km/h. During 8 km/h all the support conditions reduced resultant breast movement compared to the C condition although these were only significant for the O and H support conditions. During 10 km/h all the support conditions reduced resultant breast movement significantly ( $p < 0.05$ ) compared to the C condition. During the two-step star jump all but the L support condition were effective in significantly ( $p < 0.05$ ) reducing resultant breast movement.

Table 2 presents the perceptual ratings of bra comfort, bra fit and breast pain after completion of the treadmill test and the two-step star jumps. Participants rated the fit of the O bra the poorest (6.69) and the fit of the H bra the best (9.00). The fit ratings for the O bra was significantly poorer compared to both the H and HIU bras. Similarly the fit ratings of the L bra, which was rated second most uncomfortable, was significantly lower compared to the



**TABLE 1.** Breast displacement (mm) during incremental treadmill activity and two-step star jumping

Plane	Support Condition	4 km/h	6 km/h	8 km/h	10 km/h	Two-step Star Jump
		Mean ( $\pm$ SD)	Mean ( $\pm$ SD)	Mean ( $\pm$ SD)	Mean ( $\pm$ SD)	Mean ( $\pm$ SD)
Resultant displacement (mm)	C	21.9 (13.1)	31.0 (4.2)	43.3 (11.8)	72.0 (15.0)	50.2 (9.4)
	O	18.3 (7.4)	22.2 (9.6)*	29.7 (13.2)*	42.9 (14.6)*	39.5 (6.9)*
	L	20.6 (3.5)	30.7 (11.2)*	36.2 (5.9)	49.8 (16.6)*	46.9 (11.3)
	M	15.9 (5.2)	21.6 (7.4)*	36.1 (12.2)	41.2 (10.7)*	36.9 (5.4)*
	H	16.6 (4.8)	21.6 (8.9)*	30.7 (9.0)*	34.7 (11.8)*	35.6 (10.1)*
	HIU	15.3 (5.8)	27.6 (11.3)*	32.3 (17.3)	36.5 (11.8)*	33.3 (9.9)*
Mediolateral displacement (mm)	C	27.3 (12.5)	32.6 (11.4)	34.0 (10.1)	48.9 (7.9)	40.0 (7.1)
	O	23.3 (13.8)	29.3 (13.6)	29.7 (13.2)*	39.7 (8.7)*	20.3 (5.0)*
	L	13.9 (3.3)*	26.6 (8.6)	38.1 (10.2)*	42.6 (6.5)	24.2 (2.3)*
	M	18.0 (5.1)*	32.0 (10.1)	26.2 (5.7)*	40.2 (8.6)*	29.7 (5.5)*
	H	23.5 (7.7)	31.5 (6.9)	29.6 (6.7)*	34.0 (9.5)*	22.8 (2.5)*
	HIU	21.9 (9.1)	25.8 (6.3)	31.0 (5.8)*	37.1 (11.4)*	23.0 (2.4)*
Anteroposterior displacement (mm)	C	26.5 (9.2)	29.0 (9.4)	45.3 (6.9)	54.4 (10.0)	43.6 (9.2)
	O	16.4 (6.4)*	29.3 (13.6)	26.2 (10.1)*	38.7 (8.9)*	14.8 (3.9)*
	L	13.2 (2.4)*	26.6 (8.6)*	38.1 (10.2)	41.7 (8.2)*	27.5 (9.2)*
	M	12.8 (4.0)*	32.0 (10.1)*	24.7 (9.9)*	34.0 (7.2)*	32.2 (6.3)*
	H	18.6 (6.5)*	31.5 (6.9)*	28.9 (8.8)*	33.0 (9.9)*	28.8 (9.7)*
	HIU	18.3 (7.0)*	25.2 (6.3)	26.2 (10.1)*	29.1 (7.6)*	24.6 (2.7)*
Superoinferior displacement (mm)	C	20.4 (11.3)	26.1 (13.3)	46.6 (18.8)	64.2 (17.0)	58.4 (10.2)
	O	18.1 (7.9)	19.8 (8.0)	28.5 (8.9)*	46.2 (15.2)*	40.6 (6.3)*
	L	20.2 (10.3)	20.4 (5.3)	35.3 (14.7)	43.2 (13.1)*	36.7 (6.3)*
	M	13.8 (7.4)*	22.4 (6.8)	27.8 (9.7)*	36.5 (16.7)*	25.1 (6.1)*
	H	17.3 (6.4)	21.9 (4.7)	29.8 (14.3)*	30.3 (10.6)*	30.6 (4.9)*
	HIU	17.2 (8.4)	22.7 (9.6)	27.2 (10.2)*	30.7 (10.4)*	27.1 (5.3)*

C: Control (no bra), O: own bra, L: low support level bra, M: medium support level bra, H: high support level bra, HIU: High impact ultimate bra; \* indicates a statistical significant difference between the support and control support condition

**TABLE 2.** Perceptual ratings of bra fit, bra comfort and breast pain after incremental treadmill test

Support Condition	Bra Fit	Bra Comfort	Breast Pain
C	N/A	N/A	3.12 (3.04) <sup>M,H,HIU</sup>
O	6.69 (2.3) <sup>H,HIU</sup>	7.06 (1.9)	2.01 (2.5) <sup>HIU</sup>
L	7.69 (2.1) <sup>H</sup>	7.24 (2.7)	2.18 (2.7) <sup>H,HIU</sup>
M	8.13 (2.1)	8.18 (2.0)	1.53 (2.6) <sup>HIU,C</sup>
H	9.00 (1.0) <sup>O,L</sup>	8.41 (2.0)	0.94 (1.6) <sup>L,C</sup>
HIU	8.63 (1.5) <sup>O</sup>	8.71 (1.4)	0.35 (0.6) <sup>O,L,M,C</sup>

C: Control (no bra), O: own bra, L: low support level bra, M: medium support level bra, H: high support level bra, HIU: High impact ultimate bra; <sup>C, O, L, M, H, HIU</sup> to the right of the parentheses indicate statistical significant ( $p < 0.05$ ) differences between the particular support conditions; N/A = not applicable

H which was the rated the most comfortable bra. There were no statistically significant differences in the perceptual ratings of bra comfort across any of the support conditions.

Ratings of bra comfort did however follow the trends evident in the ratings of bra fit. Correspondingly the O bra was rated as the least comfortable bra (7.06); while the HIU bra was rated as the most comfortable bra (8.71) although it was rated only second best for fit. Expectedly breast pain was rated highest for the control condition (3.12), while for support conditions, ratings of breast pain was the highest while wearing the L bra and lowest (least painful) while wearing the HIU bra. The HIU bra significantly ( $p < 0.05$ ) reduced perceptual ratings of breast pain compared to the O, L and M bras.

The majority of the correlations between breast displacement (resultant, mediolateral, anteroposterior and superoinferior) and perceptions of breast pain were non-significant and weak and only four non-significant moderate correlations were found. One of the four moderate correlations was between ratings of breast pain and anteroposterior displacement during the C condition ( $\rho = 0.41$ ). The remaining three correlations were all between ratings

of breast pain and resultant breast displacement for the C ( $\rho = 0.34$ ), L ( $\rho = 0.37$ ) and the HIU ( $\rho = 0.39$ ) conditions.

Numerous strong and significant ( $p < 0.05$ ) correlations existed between the participants' ratings of breast pain and their perceptions of bra comfort and fit. Breast pain was significantly ( $p < 0.05$ ) and strongly correlated (with a negative slope, so that increases in breast pain ratings correlated with lower ratings of bra fit and comfort) to perceptions of both bra comfort and fit for all the conditions except the L condition. These correlations ranged between -0.93 and 0.99. For the L condition breast pain was only correlated to bra fit but not comfort. This same trend was evident for the relationship between bra comfort and bra fit which was significantly ( $p < 0.05$ ) and strongly correlated for all support conditions except the L condition.

## **Discussion**

It has been established that the correct amount of breast support and the correct fit of sports bras are required to prevent mastalgia, long term complications and sag in breast tissue.<sup>8</sup> This study investigated the effectiveness of a range of sports bras and participants' own bras in reducing multi-planar breast displacement during treadmill running and a performance of a two-step star jump. It furthermore assessed possible relationships between perceptions of bra fit, bra comfort and breast pain in relation to measured breast displacement. Results indicate that resultant breast displacement increased correspondingly with treadmill speed across all support conditions, this supports the correlation between breast displacement and treadmill speed (as the speed increases so will breast displacement up to a certain level) as previously described by Milligan et al.<sup>16</sup> Former research by Scurr and colleagues indicated significant increases in multi-planar breast displacement from walking to running without breast support,

however as running speed increased above 10km/h a plateau was observed in breast displacement.<sup>7</sup> Thus while evidence supports the increase of breast movement with corresponding increases in gait velocity, it does however appear that unsupported breast movement will only show corresponding increase up to running speeds of approximately 10km/h. Evidence clearly supports the benefits of breast support resulting in reduced breast movement. However, previous research results suggests that there might not be a need for activity level-specific breast support above lower intensity thresholds (>10km/h) and that in future research may not need to monitor unsupported breast movement above this running speed in future.<sup>17</sup>

The first important finding of this study was that not all the bras significantly reduced resultant breast movement compared to a control condition (Table 1). For instance there was no significant ( $p>0.05$ ) reduction in resultant breast movement by any of the bras during walking at 4km/h while all the bras significantly ( $p<0.05$ ) reduced resultant breast movement compared to the C condition at 10km/h treadmill running. Secondly it is evident that all the bras did not consistently reduce resultant breast movement significantly at all speeds during the treadmill test. The L, M and HIU bras had no significant effect on resultant breast movement at either 4 km/h or 8 km/h however was effective ( $p<0.05$ ) in reducing resultant breast movement at 6 km/h and 10 km/h. Thirdly it was interesting to note that a different bra performed best (greatest reduction in resultant breast movement) during each of the treadmill running speeds. The HIU bra performed best at 4 km/h. During running at 6km/h the M and H bras equally performed the best. The O bra performed best at 8 km/h, while the H bra performed the best during running at 10 km/h. The HIU bra performed best during performance of the two-step star jump. While it is evident that different bras performed best at different running speeds and jumping the L support bra consistently performed the worst (least reduction in resultant breast movement) across all running speeds and the jumping test.

Previous research by Zhou, Yu, and Ng have found that an encapsulating bra is more effective at decreasing anteroposterior and mediolateral breast displacement compared to a compression bra design, especially at higher exercise intensities.<sup>18</sup> The bras used in this study were of an encapsulating design except for the L support level bra and therefore the results are in agreement with that of Zhou et al.<sup>18</sup> specifically at higher treadmill speeds. It is also important to mention that the O bra did not consistently perform well at reducing breast displacement in all the planes and including resultant displacement. This may once again highlight the importance of selecting the correct exercise bra and ensuring it fits properly.<sup>1</sup>

Considering these findings it is apparent that resultant breast movement and the reduction of such movement is a multifaceted function of breast size, bra design and movement/activity type. The variance in the best performing bra for reduction in resultant breast movement at each of the different treadmill running speeds highlights this fact and indicates that sports bras should be carefully selected to best suit the activity type and breast size of the wearer. This variance in best suited bra for each of the running and jumping conditions is further evident when considering the reduction of the mediolateral, anteroposterior and superoinferior movements of the breast. Similar to the results for resultant breast movement, a different bra (Table 1) performed best during each of the treadmill running speeds for each of the individual contributing components of resultant breast movement. A possible limitation of our study would be that the participants were relatively small breasted and our results cannot predict whether the same variance in performance of the bras would be observed in larger breasted women and/or different activity levels.

The results of the perceptual ratings indicate that the O bra was rated lowest for both bra fit and comfort and second highest for breast pain. This finding is surprising and raises questions regarding individual bra choice and perhaps knowledge of appropriate fit and sizing. This result is surprising considering that the O bra performed best in reducing

resultant breast movement for two of the treadmill speeds and outperformed the L bra for all the test conditions inclusive of the jumping task. This result is however supported by the lack of any significant ( $p < 0.05$ ) and mostly weak to moderate correlations between perceptual ratings of breast pain and resultant breast displacement. The strongest correlation between breast pain and breast displacement was found for anteroposterior displacement during the C condition ( $p = 0.42$ ).

Previous studies have suggested that breast pain is felt with the stretching of the supporting structures, skin and fascia of the breast and can occur with repeated loading of the breast with physical activity and this could result in breast sag.<sup>6</sup> Although these relationships appear to be expected, they were not evident in our study. This is contrary to the findings of previous studies, linking in particular movement in the superoinferior plane to breast pain.<sup>14</sup> It is suggested that the biggest contributor to an increase in breast displacement is not in the acceleration experienced by the breast tissue but rather the superoinferior displacement.<sup>11</sup> The lack of such relationships in our study indicates that breast displacement may not play a critical role in ensuing breast pain in our participants.

An important finding of our study is that, for our particular group of participants, perceptual ratings of bra fit and comfort were a stronger and more reliable predictor of breast pain than objectively measured breast displacement. This is based on significant ( $p < 0.05$ ) and strong correlations (ranging between -0.99 and 0.99) found between both bra comfort and fit with breast pain for all the support conditions except for the L condition. What our study fails to answer is whether the lack of a relationship between breast displacement and pain is a function of the relatively smaller breasted participants or perhaps a lack of sensitivity in the instruments used to record perceptions of the participants. However, considering the strong relationship between perceptions of bra fit, comfort and breast pain we suggest that breast displacement is perhaps not a key contributor to breast pain in smaller breasted women.

Additional investigations into biomechanical variables such as breast velocity and acceleration should be investigated in order to enhance our understanding of the possible relationship between breast movement and breast pain in small breasted exercising women. Previous studies have shown a correlation between breast pain and breast displacement and velocity.<sup>4,19</sup> Although our study did not investigate the relationship between breast comfort and breast velocity, a recent study found breast velocity to be strongly correlated to breast comfort during exercise.<sup>11</sup> Important limitations of this study include the small sample size and that larger breasted women (D cup and larger) were not included in this study.

### **Conclusions**

In conclusion our results highlighted the variance in performance of a range of sports bras in reducing breast displacement during exercise. Not all the bras consistently reduced breast movement significantly at all treadmill speeds. These variances emphasise the need for careful selection of type of bra and proper fit in order to provide optimal support during activity. Contrary to previous research we found weak and non-significant relationships between perceptual ratings of breast pain and breast movement. Perceptual ratings of bra fit and bra comfort were stronger and more reliable predictors of breast pain in our group of relatively small breasted participants.

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