Applied Ergonomics

**TITLE:**

The Impact of Breast Support Garments on Fit, Support and Posture of Larger Breasted Women.

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**Abstract**

Due to current measurement, sizing and fitting approaches, poor bra fit is prevalent amongst larger breasted women. The impact of improving bra fit hasn't yet been explored. This pre-clinical study aimed to explore immediate and short-term biomechanical responses to changing breast support garment. Asymptomatic participants (n=24) performed a static standing task, drop jumps and seated typing whilst kinematic data from the breasts and spine were recorded. Three breast support conditions were assessed: Usual, professionally fitted bra in the immediate term (PFB), and the same professionally fitted bra after four weeks wear (PFB28). Bra fit assessments were included for both bras. All participants failed the bra fit assessment when wearing the Usual bra and 67% (n=16) failed when wearing the PFB. Less bra fit issues were present in the PFB, resulting in immediate biomechanical changes relating to breast support and spinal posture, yet nothing in the short term (PFB28). This research sets the foundations for future work to investigate whether the implementation of better fitting breast support garments can influence musculoskeletal pain amongst larger breasted women, whilst attributing potential improvement of symptoms, objective measures of breast support and spinal posture.

**HIGHLIGHTS:**

- Use of professional bra fitting services do not guarantee correct bra fit for larger breasted women.
- Nipple-Sternal-Notch distance may be an appropriate measure of uplift applied to the breast by a bra.
- Improving bra fit may be useful for prevention / conservative rehabilitation of chronic back pain.
- Revision of bra design, sizing, and measurement approaches for large breasted women is advised.

**Keywords**

Breast support

Bra fit

Breast biomechanics

**Abbreviations**

NSN – Nipple-Sternal-Notch

PFB – Professionally-fitted bra in the immediate term

$PFB_{28}$ – Professionally-fitted bra after a 4-week intervention period

UB – Usual bra

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## 1. INTRODUCTION

The bra is one of the most intimate items of clothing a woman wears (White and Scurr, 2012). Its purpose is to support breast weight, provide comfort, and satisfy breast aesthetics through prevention of sagging (Yu et al., 2006; Sun et al., 2011; Pei et al., 2019). Bras are conventionally sized using the alphabet sizing system, considering under and over bust circumferential measurements to determine band (32, 34 etc) and cup (A, B etc) size (Wright, 2001). These sizing principles have been used since the development of the bra in 1914, likely because it is necessary to accurately communicate bra sizes between key stakeholders including customers, retailers, manufacturers and designers (White and Scurr, 2012). Due to a lack of standardisation and varying interpretations of measurement and sizing guidelines, the ability to accurately communicate consistent bra sizes is regularly compromised (White and Scurr, 2012; Pei et al., 2019), potentially accounting for why the majority (75-100%) of women persistently wear the wrong size bra, worldwide (Pechter, 1998; Page and Steele, 1999; Greenbaum et al., 2003; McGhee and Steele, 2010; McGhee et al., 2010; Odebiyi et al., 2015; Coltman et al., 2018a).

As breast size increases, measuring for bra size becomes more difficult, due to the reduced ability to correctly record breast measurements, owing to varied soft tissue distribution with the presence of bulbous and ptotic tissue (Chen et al., 2011). As larger breasted women (D+) also commonly present with elevated Body Mass Indexes (Brown and Scurr, 2012), the measuring tape may migrate between skin tissue folds with no clear distinction between breast tissue and the upper abdomen (Pandarum et al., 2011). An absence of standardisation relating to the woman's position (Pechter, 1998), the breasts' position (Greenbaum et al., 2003) and the phase of respiratory cycle (McGhee and Steele, 2006) may also provide further reasoning as to why so many women fail to select the correct size bra, even when professionally fitted (Pechter, 1998; Page and Steele, 1999; Greenbaum et al., 2003; McGhee and Steele, 2010; McGhee et al., 2010; Odebiyi et al., 2015; Coltman et al., 2018a).

It has been proposed that consistent wearing of an ill-fitting bra may be a causal mechanism for the development of musculoskeletal pain amongst larger breasted women, due to the lack of external support offered to the breasts (Spencer and Briffa, 2013; Odebiyi et al., 2015; Coltman et al., 2018b). The shoulder straps of the bra were originally designed as secondary support to align the bra vertically on the body (Zhou et al., 2013; Coltman et al., 2018b). If the bra's cups are too big, or the underband is too tight, the shoulder straps then absorb the weight of larger breasts, increasing compressive forces through the shoulders, resulting in the gradual onset of ischaemia within the trapezius muscles (Odebiyi et al., 2015). The continuous downward drag of breast weight through the shoulder straps may contribute to the development of pain within the posterior aspect of the lower cervical, upper thoracic and scapula region (Edward, 2000; Spencer and Briffa, 2013). In turn, the scapula retractors may become lengthened due to involuntary protraction, caused by a poorly supported heavy load on the anterior chest wall (Edward, 2000; Spencer and Briffa, 2013). If poorly supported, breast weight may pull the upper thoracic and cervical vertebra anteriorly, protracting the shoulders, closing the chest and restricting normal neck, shoulder and upper torso function (Greenbaum et al., 2003). This prolonged mechanical adaptation may contribute to the development of chronic Back Pain over time.

Poor bra fit compromises bra function, contributes to painful symptoms, reduces breast support and results in unfavourable spinal mechanics and postures (Page and Steele, 1999). Although the introduction of a correctly fitted bra may alleviate symptoms by up to 85% (Hadi, 2000; Greenbaum et al., 2003), research investigating this is sparce. It is expected that the prevalence of musculoskeletal pain amongst larger breasted women will continue to rise globally due to the increasing trend in bra size. Average British bra size is currently a 36DD , whilst twenty years ago it was a 34B (McGhee et al., 2018). Similarly, in the USA the current average bra cup size is a D cup, although there is no reference to average band size (WorldData.Info, 2021). With this in mind, it is essential to better understand exactly what influence current bra designs, and fitting services have on larger breasted women.

This study aimed to explore the impact of a professionally fitted bra in both the immediate term, and after a short-term intervention period of 4 weeks. Differences in bra fit quality, and objective, biomechanical parameters relating to breast support and postural characteristics were explored amongst a larger breasted, healthy cohort. It was hypothesized that improvements in bra fit quality may result in changes in objective measures of breast support and posture.

## 2. METHODS

### 2.1. Participants

This preliminary pre-clinical study (Anderson, 2008) was designed to confirm a feasible protocol for future clinical studies recruiting symptomatic chronic back pain patients and to enable comparisons of different breast support garment designs which may address the problems associated with current bra design, sizing and fitting principles. The University Ethics Committee approved this study (STEMH241) and written informed consent was provided by all participants. The study included twenty-four larger breasted (D+) women (mean age 31 years; range 20-51 years), who were free from back pain in the 3 months before recruitment. A strict screening process (Greenhalgh and Selfe, 2010) was implemented to identify and exclude anybody with potential indicators of serious pathology. Pregnant and breast feeding women, or anyone who had a history of breast surgery were also excluded from the study (McGhee and Steele, 2006; McGhee et al., 2010, 2013).

## 2.2. Study Design

A ten camera Qualisys motion analysis system (Qualisys Medical AB, Gothenburg, Sweden) was used to collect breast kinematics and spinal posture data over two sessions, separated by a four-week intervention period. At the first session, data was collected in each participant's own usual bra (UB), and in a brand new professionally fitted bra (PFB), to afford analysis of the bra in the immediate term. Participants then wore the PFB as much as possible for four weeks and at the second data collection session, participants were re-tested in the PFB ($PFB_{28}$) to assess the effects of the intervention period. To offer ecological validity to the study, the PFBs were fitted at high street retail stores who offered a professional bra fitting service by bra fitters who were blinded to the study. To emphasise, the PFB condition used a professional bra fitting service, but did not guarantee correct fit, which is why a bra fit assessment was included within the protocol. The PFB had to be full cupped, with straps and not a sports bra. Anthropometric measurements (height, weight, and circumferential measurements) and UB and PFB bra sizes were recorded at the first session. Chest, waist, and hip circumferences were all measured in centimetres (cm), using a standard flexible measuring tape, and the average of three recordings was used. Chest circumference was measured with the tape extended around the fullest part of the bust (Brown et al., 2012). Waist circumference was measured from the tip of the iliac crest, and hip circumference was measured at the broadest part of the hips, in line with published guidance (Al-Gindan et al., 2014).

## 2.3. Experimental Protocol

### 2.3.1. Bra Fit Assessment

A bra fit assessment was carried out by the researchers (LH, JJ, AC) in the UB and PFB to evaluate bra fit quality. This process assesses the fit of component parts of the bra (cup, band, straps, underwire etc.) against set criteria, and has previously been used in breast related research (McGhee and Steele, 2010; White and Scurr, 2012). The presence of one or more of the bra fit issues (Table 2.1), which could not be eliminated with strap or hook adjustment indicated incorrect fit, and a failed assessment.

**Table 2.1: Professional 'best fit' bra fitting criteria (McGhee and Steele, 2010)**

| Bra component | Potential bra fit issues |
|---|---|
| Band | Too tight: flesh bulging over top of the band; subjective discomfort "feels too tight"<br>Too loose: band lifts when arms are moved above head, posterior band not level with inframammary fold |

| | |
|---|---|
| Cup | Too big: wrinkles in cup fabric<br>Too small: breast tissue bulging above, below or at the sides |
| Underwire | Incorrect shape: underwire sitting on breast tissue laterally (under armpit) or anterior midline; subjective complaint of discomfort. |
| Straps | Too tight: digging in; subjective complaint of discomfort; carrying too much of the weight of the breasts<br>Too loose: sliding down off shoulder with no ability to adjust the length |
| Front band | Not all in contact with the sternum |
| Bra fit rating | **Pass:** None of the above identified.<br>**Fail:** Identification of one or more bra fit issues |

#### 2.3.2. Self-reported bra fit issues

Based on criteria from the bra fit assessment (McGhee and Steele, 2010; White and Scurr, 2012), participants were asked to subjectively report their experiences of common bra fit issues using a 5 point Likert scale; never, rarely, sometimes, very often, always (Table 3.2). This was performed for participants' UB and for the PFB after 4 weeks wear.

#### 2.3.3. Biomechanical Data Collection

Breast kinematics during a drop jump from a 20cm high step, and intersegmental, multiplanar spinal posture in a standing and seated position was explored. A review of previous breast biomechanics research suggests that the supportive capabilities of a bra can be best determined using an activity which induces vertical breast displacement (McGhee and Steele, 2020) and as such a vertical jump task was considered a suitable activity to measure the supportive capabilities of the breast support conditions included within this study. A static measure of breast position was also collected with participants in standing to provide a static measure of breast position on the anterior chest wall at rest. Participants were given two marker set options; [1] an adapted T-shirt which facilitated recording of spinal movement data but covered the breasts and stomach; [2] wear only the breast support garment and lower limb clothing which also enabled recording of breast kinematic data.

Following calibration of the capture space to ensure a measurement error of less than 0.5mm, retro-reflective markers, 9.5mm in diameter, were placed on palpable anatomical landmarks to define specific body segments (Cappozzo et al., 1995). A total of 41 (T-shirt) or 51 (no-T-shirt) markers were applied bilaterally to each participant over the acromions, anterior superior iliac spines, posterior superior iliac spines, calcanei, and suprasternal notch. A four-marker pelvic cluster was used, and spinal marker clusters (Figure 2.1) were placed to define four spinal segments; C7 – Upper Thoracic (UT), T7 – Lower Thoracic (LT), L3 – Upper Lumbar (UL) and L5 – Lower

Lumbar (LL), as seen in previous postural analysis research (Chohan et al., 2013, 2019). The spinous process of C7 was found by identifying the anterior movement of C6 during cervical extension, and then by palpating down one spinous process (Robinson et al., 2009). T8 was located by following an imaginary horizontal line from the inferior angle of the scapula (Cooperstein and Haneline, 2007). Although it has previously been disputed whether T7 or T8 corresponds with the inferior angle of the scapula (Haneline et al., 2008), by using this method of palpation, repeatability and reliability of identifying the same spinal level is high (Cooperstein and Haneline, 2007). At the lumbar region of the spine, L3 and L5 were identified by palpating the first spinous process above (L3) and the first spinous process below (L5) the horizontal line of the iliac crests (Seffinger and Hruby, 2007; Robinson et al., 2009). Initial pilot testing demonstrated that it was difficult to track the anterior inferior iliac spine markers, particularly during seated tasks where markers were often hidden by soft tissue, which necessitated the inclusion of a four marker pelvic cluster within the marker set to ensure marker visibility throughout tasks.

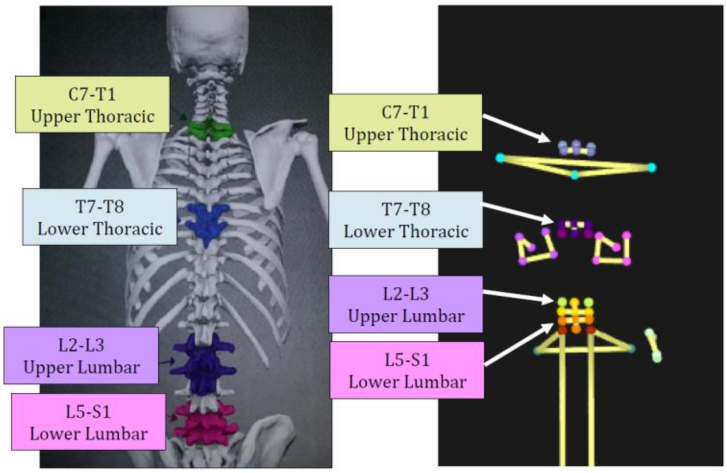


*Figure 2.1: [Left] Skeletal diagram of spinal marker set used for data collection (Primal Pictures, 2016). [Right] Screenshot of marker set, taken from Qualisys Track Manager (QTMv.2.13; Qualisys AB, Sweden)*

For those participants who consented to collecting breast kinematics, five markers were attached to each cup of the bra to create two breast segments. The first marker was placed directly over the nipple and then a template was used to ensure the other four markers were placed equidistance around the central marker.

### 2.4. Data Processing and Analysis

All movement data was collected using Qualisys Track Manager (QTM v2.13; Qualisys AB, Sweden). Raw co-ordinate data was imported into Visual 3D (Version 6.01.08, C-Motion, Maryland, USA) in c3d format for processing.

Nipple-Sternal-Notch (NSN) distance (Figure 2.2) was recorded as a measure of static breast position and calculated using a multistep process. In Visual 3D, left and right nipple marker signals were subtracted from the sternal notch marker in the X, Y and Z axis. This data was exported into Microsoft Excel 2016 (Microsoft Corp, USA) where the mean and standard deviations were calculated from the normalised data. NSN distance was then calculated, in cm, using a three-dimensional Pythagorean equation:

$$NSN\ Distance\ (cm) = \sqrt{x^2 + y^2 + z^2}$$

$$Excel\ Formula = SQRT(X^2 + Y^2 + Z^2)$$

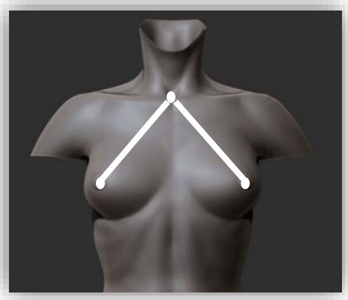

*Figure 2.2: Nipple-to-Sternal Notch (NSN) distance*

From the drop jump data, breast displacement was calculated in three directions: mediolateral, anterior-posterior and superior-inferior. The exact location of the left and right breast marker clusters were calculated relative to the bony lower thoracic marker cluster, enabling analysis in 3 planes, from the point at which the participant's feet left the step, to the point at which the ASIS markers ceased moving upwards after landing. The left and right breast were selected as the targeted segments, with the reference segment and resolution co-ordinate system set as the lower thoracic segment. The X, Y and Z data signals were exported into Microsoft Excel where the minimum and maximum value for the three signal components were identified. To calculate the displacement in each direction during the jump, the difference between the minimum and maximum value was calculated.

Intersegmental spinal posture was calculated in standing and sitting statures. The exact position of each spinal marker segment relative to another was identified during five, two-second measurements throughout the duration of a 30 second standing and typing task (Kuo et al., 2019). Five measurements were included to ensure stability of the data over time. A longer task may have facilitated unwanted participant fatigue. Intersegmental spinal analysis focussed on relative position between:

- Upper thoracic relative to the lower thoracic region

- Upper lumbar relative to the lower lumbar region
- Lower lumbar relative to the pelvis.

Changes in intersegmental spinal posture were calculated in three movement planes: flexion/extension (X), left/right side flexion (Y), left/right rotation (Z). The normalised X, Y and Z components of the signals were exported into Microsoft Excel where the mean values were calculated. Spinal analysis using the torso as a single segment was then also carried out by assessing the trunk's (defined as the left/right acromion and LT segment) position relative to the pelvis (Left/right posterior superior inferior spine, pelvic cluster).

### 2.5. Statistical Analysis

Measures of central tendency were computed to summarize the data for self-reported bra fit issues. Breast kinematic data (NSN distance and breast displacement), which consisted of normally distributed parametric data considered the effect of both side (left/right) and breast support condition (UB, PFB, $PFB_{28}$) using 2 x 3 repeated measures ANOVAs . For intersegmental spinal posture, the effect of different breast support conditions (UB, PFB, $PFB_{28}$) was assessed using a repeated measures ANOVA. Statistical significance was set at $p<0.05$.

## 3. Results

Anthropometric data and participant demographics are listed in Table 3.1.

**Table 3.1: Participant (n=24) anthropometric measurements – Mean (SD) and range.**

| Measurement | Mean (SD) | Range |
|---|---|---|
| Age (years) | 30.9 (9.7) | 20 – 51 |
| Height (m) | 1.7 (0.008) | 1.50 – 1.80 |
| Weight (kg) | 77.5 (19.8) | 47.30 – 122.80 |
| BMI ($kg/m^2$) | 28.2 (6.3) | 18.95 – 42.49 |
| Chest circumference (cm) | 102.1 (10.7) | 83.17 – 128.00 |
| Waist circumference (cm) | 84.6 (13.1) | 59.17 – 116.93 |
| Hip circumference (cm) | 108.8 (14.5) | 87.17 – 141.83 |
| Waist-Hip Ratio | 0.78 (0.04) | 0.68 – 0.86 |

The modal UB size amongst participants was 32DD (cup size range DD – HH, band size range 30 – 42). Five participants (21%) were professionally fitted with the same bra size as the UB. There was a maximum of two band size differences between participants' UBs and PFBs. Five (21%) participants wore a larger band size in the PFB, ten (42%) wore a smaller band size and nine (37%) participants had the same band size in both conditions. For cup size, ten (42%) participants had the same cup size in both bras, eleven (46%) increased cup size in the PFB and three (12%) reduced cup size.

### 3.1. Bra fit assessment

All participants (100%) failed the bra fit assessment in the UB and sixteen (67%) participants failed in the PFB. In the UB, 77 bra fit issues were identified amongst all participants (average 3.2 per bra, range 1-5), and all but one of the UBs failed with multiple fitting issues. Figure 3.1 demonstrates that the most common bra fit issues in the UB were large cups (63%, n=15), the front band not being in contact with the sternum (58%, n=14) and loose straps (50%, n=12). In the PFBs, there were 29 bra fit issues amongst all participants (average 1.2 per bra, range 0-4, 62% improvement compared to the UBs) and 38% of participants failed on only one aspect of the assessment. The most common bra fit issues in the PFB were the front band not being in contact with the sternum (29%, n=7), large cups (25%, n=6) and a tight band (25%, n=6).

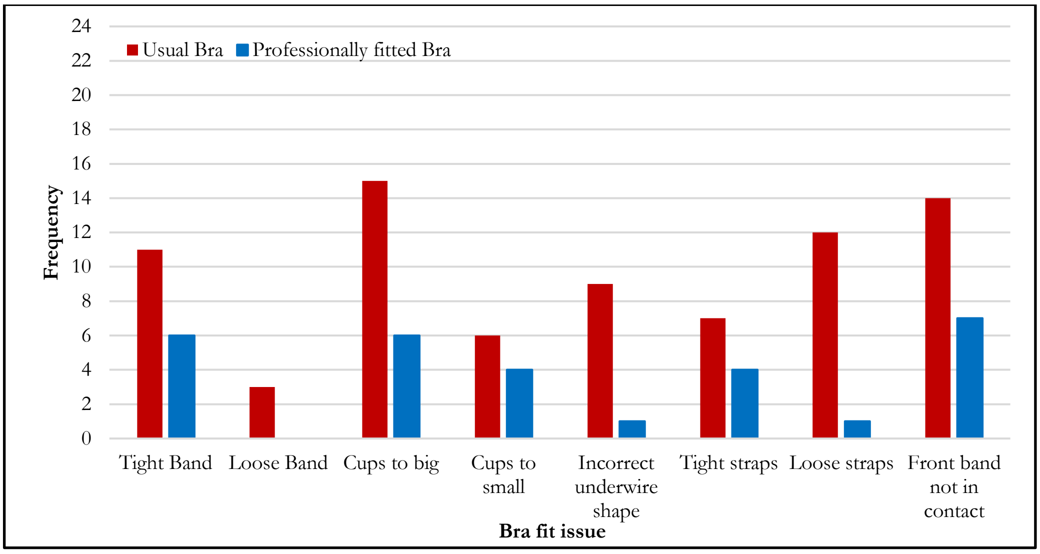


*Figure 3.1: Bra fit assessment results*

### 3.2. Self-reported bra fit issues

The central tendency for all variables in the PFB were 'never', suggesting that most participants felt each bra fit issue was not present in the PFB (Table 3.2). In contrast, for the UB there were greater variances in response, but the most frequent reports were rubbing chaffing (sometimes, 42%), a tight band (sometimes, 33%), bulging breast tissue (very often, 38%) and the front of the bra not being in contact with the body (sometimes, 29%).

**Table 3.2 Participants (n=24) self-reported bra fit issues. Highlighted text indicates the central tendency per variable**

| | Never | Rarely | Sometimes | Very Often | Always |
|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| **Rubbing/chaffing occurs** | UB | 5 (21%) | 6 (25%) | 10 (42%) | 2 (8%) | 1 (4%) |
| | PFB | 12 (50%) | 5 (21%) | 5 (21%) | 1 (4%) | 1 (4%) |
| **Shoulder straps dig in** | UB | 8 (32%) | 0 (0%) | 8 (32%) | 6 (25%) | 2 (8%) |
| | PFB | 11 (44) | 5 (21%) | 6 (25%) | 2 (8%) | 0 (0%) |
| **Upper body muscle pain** | UB | 15 (63%) | 4 (17%) | 4 (17%) | 1 (4%) | 0 (0%) |
| | PFB | 19 (79%) | 3 (12%) | 2 (8%) | 0 (0%) | 0 (0%) |
| **Poor posture** | UB | 12 (50%) | 5 (21%) | 5 (21%) | 2 (8%) | 0 (0%) |
| | PFB | 16 (67%) | 7 (29%) | 1 (4%) | 0 (0%) | 0 (0%) |
| **Underwire digs in** | UB | 3 (13%) | 7 (29%) | 7 (29%) | 5 (21%) | 2 (8%) |
| | PFB | 13 (54%) | 4 (17%) | 5 (21%) | 1 (4%) | 1 (4%) |
| **Band too tight** | UB | 6 (25%) | 6 (25%) | 8 (33%) | 2 (8%) | 2 (8%) |
| | PFB | 11 (46%) | 9 (38%) | 4 (17%) | 0 (0%) | 0 (0%) |
| **Breast tissue bulges over the cup** | UB | 5 (21%) | 3 (13%) | 6 (25%) | 9 (38%) | 1 (4%) |
| | PFB | 13 (54%) | 6 (25%) | 5 (21%) | 0 (0%) | 0 (0%) |
| **Wrinkling of the bra cup** | UB | 12 (50%) | 7 (29%) | 2 (8%) | 3 (13%) | 0 (0%) |
| | PFB | 17 (71%) | 4 (17%) | 3 (13%) | 0 (0%) | 0 (0%) |
| **Front of bra not in contact with the body** | UB | 6 (25%) | 4 (17%) | 7 (29%) | 6 (25%) | 1 (4%) |
| | PFB | 14 (58%) | 5 (21%) | 2 (8%) | 1 (4%) | 2 (8%) |

### 3.3. Nipple-Sternal-Notch Distance

Of the 24 participants recruited to the study, 16 (66%) permitted recording of breast kinematics. Whilst there was no significant effect of side in NSN distance (p=0.768), there were significant interactions between breast support conditions; when first put on, the PFB significantly reduced NSN distance compared to the UB by 0.6cm (p=0.010). The NSN distance in the $PFB_{28}$ however, was not significantly different to the UB or the PFB (p>0.258) (Table 3.3).

**Table 3.3: Mean (SD) NSN distances and breast displacement (cm). Mediolateral, anterior posterior and superior inferior breast displacement.**

| | | UB | PFB | $PFB_{28}$ |
|---|---|---|---|---|
| NSN Distance (cm) | Mean | 22.3 (2.2) | **21.7 (2.1)** $^{B}$ | 21.9 (2.0) |
| Breast Displacement (cm) | Mediolateral | 1.1 (0.3) | **1.0 (0.2)** $^{B}$ | **1.1 (0.3)** |
| | Anterior posterior | 1.1 (0.4) | **0.9 (0.4)** $^{B}$ | 1.0 (0.4) |
| | Superior inferior | 4.1 (1.4) | 3.8 (1.4) | 4.0 (1.2) |

$^{A}$ indicates significance within bra
$^{B}$ indicates significance compared to UB

### 3.4. Breast Displacement

Like NSN distance, there was no significant effect of side in mediolateral, anterior posterior and superior inferior breast displacement (p>0.141). There were significant interactions between breast support conditions; the PFB immediately significantly reduced mediolateral displacement compared to the UB (p=0.041), although actual change was only 0.1cm. The PFB significantly reduced anterior posterior displacement compared to the UB (p=0.002) by 0.2cm. There was no significant difference between breast support conditions when considering superior inferior displacement (p>0.455). Although the greatest magnitudes of displacement occurred in the superior inferior direction, the bras provided comparable levels of support.

### 3.5. Standing Posture

Changing breast support garment had a significant effect on Upper Thoracic spinal posture (Figure 3.2, left) in the sagittal plane; the PFB significantly reduced thoracic flexion by 2.5° compared to the UB (p=0.004; Table 3.4). After four weeks however, thoracic flexion significantly increased, by 5.7° compared to the PFB (p=0.021), positioning participants into a more forwardly flexed posture than both the PFB and UB. There were no significant differences in side flexion or rotation at the upper thoracic region (p>0.505).

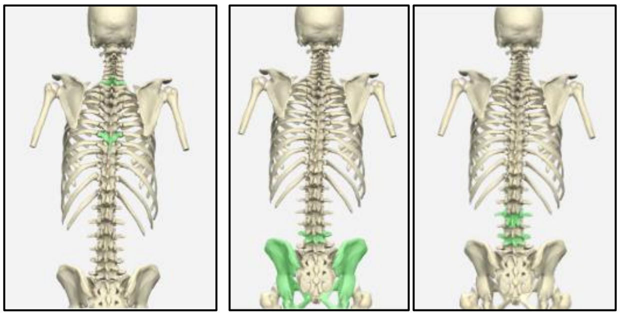

*Figure 3.2: [Left]Upper thoracic region relative to lower thoracic region. [Centre] Lower lumbar relative to pelvis. [Right Upper lumbar region relative to lower lumbar region (Primal Pictures, 2016).*

Spinal posture did not significantly change in any direction at the Lumbar region because of changing breast support garment (p>0.534). Nonetheless, when comparing between the lower lumbar region and the pelvis (Figure 3.2, centre), after four weeks wear the $PFB_{28}$ significantly increased the amount of right rotation by 1.7° compared to the PFB (p=0.009).

**Table 3.4: Mean (SD) change in intersegmental spinal posture in standing, comparing between breast support conditions.**

| | Comparison | Flexion - Extension | Side-Flexion | Rotation |
|---|---|---|---|---|
| Upper thoracic relative to lower thoracic | PFB v UB | **+2.5° (3.9)**[b] | -0.2° (2.0) | +0.6° (1.9) |
| | $PFB_{28}$ v UB | -3.2° (11.2) | -0.9° (5.7) | +0.6° (4.6) |
| | $PFB_{28}$ v PFB | **-5.7° (11.3)**[a] | -0.8° (5.5) | -0.56° (5.4) |
| | PFB v UB | -0.1° (9.4) | +0.3° (2.7) | +0.1° (13.7) |

| | | | | |
|---|---|---|---|---|
| Upper lumbar relative to lower lumbar | $PFB_{28}$ v UB | -0.0° (14.1) | -0.8° (6.9) | -1.1° (6.3) |
| | $PFB_{28}$ v PFB | +0.1° (13.7) | +0.2° (2.6) | -0.1° (3.1) |
| Lower lumbar relative to the pelvis | PFB v UB | -0.1° (5.3) | +0.4° (1.6) | -0.7° (2.5) |
| | $PFB_{28}$ v UB | +0.3° (9.1) | -0.7° (4.3) | +1.0° (3.4) |
| | $PFB_{28}$ v PFB | +0.3° (10.0) | -1.1° (4.3) | **+1.7° (3.0)[a]** |
| Trunk relative to the pelvis | PFB v UB | +1.2° (3.8) | +0.7° (1.9) | -0.7° (3.4) |
| | $PFB_{28}$ v UB | -0.1° (10.5) | -0.2° (4.5) | -0.2° (4.6) |
| | $PFB_{28}$ v PFB | -1.3° (10.4) | -0.8° (4.4) | +0.5° (5.1) |

Flexion-Extension: + indicates movement towards extension, - indicates movement into flexion
Side Flexion / Rotation: + indicates movement to left, - indicates movement to right
[a] indicates significance within bras (PFB v PFB28), [b] indicates significance compared to Usual (Usual v PFB or Usual v PFB28).
PFB – Professionally Fitted Bra in the immediate term, $PFB_{28}$ - Professionally Fitted Bra post four-week intervention period, UB – Usual Bra

### 3.6. Sitting Posture

Changing breast support garment had no significant effect on Upper Thoracic posture (p>0.070). At the Lumbar region (Figure 3.2, right), sitting posture was affected in both the sagittal and transverse plane (p<042). Post intervention, lumbar lordosis significantly increased by 4.1° compared to the UB (p<0.035; Table 3.5). In the transverse plane, post intervention, participants moved into a significantly different left rotated posture, compared to the UB and PFB (p<0.030).

At the lumbar-pelvic region (Figure 3.3), sitting posture was also affected in the sagittal and transverse plane (p<0.001). The PFB significantly increased extension, and therefore lumbar lordosis and anterior pelvic tilt compared to the UB and $PFB_{28}$ (p<0.017). In the transverse plane, the PFB significantly changed the rotational position of the pelvis relative to the lower lumbar region from a left rotated position in the UB to a right rotated position (p=0.002). This change then significantly increased by 3.3° in the $PFB_{28}$ condition (p=0.001). There was no significant difference in trunk position relative to the pelvis because of change in breast support condition (p=0.099).

**Table 3.5: Mean (SD) change in intersegmental spinal posture in sitting, comparing between three breast support conditions.**

| | Comparison | Flexion - Extension | Side-Flexion | Rotation |
|---|---|---|---|---|
| Upper thoracic relative to lower thoracic | PFB v UB | +2.0° (3.9) | +0.4° (2.4) | -0.3° (1.8) |
| | $PFB_{28}$ v UB | -3.1° (11.4) | -1.2° (5.7) | +0.4° (4.6) |
| | $PFB_{28}$ v PFB | -5.1° (11.6) | -1.6° (5.9) | +0.1° (5.3) |
| Upper lumbar relative to lower lumbar | PFB v UB | +0.4° (3.7) | +0.4° (2.1) | +0.3° (1.0) |
| | $PFB_{28}$ v UB | **+4.1° (8.9)[b]** | -0.8° (6.2) | **-1.3° (2.7)[b]** |
| | $PFB_{28}$ v PFB | +3.7° (9.0) | -1.1° (6.1) | **-1.6° (2.4)[a]** |
| | PFB v UB | **+11.0° (13.4)[b]** | -0.3° (4.5) | **-2.5° (3.5)[b]** |

| | | | | |
|---|---|---|---|---|
| Lower lumbar relative to the pelvis | $PFB_{28}$ v UB | +3.7° (9.6) | -0.6° (5.4) | +0.8° (4.0) |
| | $PFB_{28}$ v PFB | **-7.3° (13.8)**[a] | -0.3° (4.8) | **+3.3° (4.5)**[a] |
| Trunk relative to the pelvis | PFB v UB | +2.2° (4.8) | +1.2° (3.3) | -0.9° (3.1) |
| | $PFB_{28}$ v UB | +3.9° (10.2) | -0.3° (3.5) | -0.6° (5.2) |
| | $PFB_{28}$ v PFB | -1.7° (8.9) | -1.5° (4.1) | +0.3° (4.4) |

Flexion-Extension: + indicates movement towards extension, - indicates movement into flexion
Side Flexion / Rotation: + indicates movement to left, - indicates movement to right
[a] indicates significance within bras (PFB v PFB28), [b] indicates significance compared to Usual (Usual v PFB or Usual v PFB28).
PFB – Professionally Fitted Bra in the immediate term, $PFB_{28}$ - Professionally Fitted Bra post four-week intervention period, UB – Usual Bra

## 4. Discussion

The aim of this research was to consider how bra fit quality changed when comparing between participants' own Usual bras, and one that had been professionally fitted using established bra fitting services. Secondary to that, collection of objective measures of breast support and spinal posture afforded the impact of bra fit quality to be quantified. Thirdly, the inclusion of a four week intervention period to measure change in outcome measures over time started to address some of the gaps previously highlighted within current literature, the main one being that to date, bras are only evaluated once, without consideration for the effect of time.

The findings of this study suggest improvements are needed to enable more larger breasted women to achieve correct bra fit and be provided with the optimum level of external level of breast support which does not compromise breast comfort or result in the development of painful symptoms. Furthermore, this study provides a feasible protocol for future clinical studies, which may help to determine whether conservative measures, such as adjusting breast support, may be beneficial for larger breasted women with chronic pain.

### 4.1. Bra fit assessment and self-reported bra fit issues

The findings from this study reinforce suggestions that current bra solutions, sizing principles and fitting procedures require revision for larger breasted women (McGhee and Steele, 2010; Swies et al., 2016; McGhee and Steele, 2020a). Achieving the correct cup and band size has proven difficult for larger breasted women, regardless of whether a professional bra fitting service has been used or not, and women continue to wear the wrong size bra (McGhee et al., 2010; White and Scurr, 2012). The present study found 41% of UBs worn by participants failed the bra fit assessment due to the underwire component, and 64% failed because the front band was not in contact with the sternum. It is known that larger breasted women are likely to experience different bra fit issues in comparison to smaller breasted women (Coltman et al., 2018). Larger breasted women specifically find it challenging to find an underwire of the correct shape and correct cup size, and also struggle to ensure the front band contacts the sternum to provide separate encapsulation of the breasts (Coltman et al., 2018). As breast size, volume and mass increase, the variance in breast shape increases, making it almost impossible for a universal shape of underwire to optimise fit (Coltman et al., 2018). The age of the bra in the Usual bra may have also influenced the assessment of bra fit quality (Pechter, 1998). Current recommendations suggest replacing a bra after six to twelve months of wear, or sooner with significant weight loss or gain (North American Spine Society, 2007; Mercer, 2016; Isokariari, 2018). Although a bra may fit at the time of purchase, wearing and laundering may cause the shape and structure of the bra to deteriorate, and this may provide reasonable explanation as to why the Usual bras in this study all failed the bra fit assessment. Although the majority (n=16, 66%) of the Usual bras in this study had been purchased in the six months before participation, conforming to commercial purchasing recommendations, the rate of bra fitting failure suggests there may be a need to revise recommendations based on other factors. Amongst the professionally fitted bras, the incidence of ill-fitting bras was still high (67%). This is in agreement with previous research which suggests that the implementation of a professional bra fitting service does not guarantee correct bra fit for everyone (McGhee et al., 2010; Spencer and Briffa, 2013). The number of overall bra fit issues did reduce in the professionally fitted bra compared to the Usual bra, and there were fewer self-reported bra fit issues after wearing the PFB, so it may be argued that there was relative success when using a fitting service. The results of the bra fit assessment further highlight the need to address the problems associated with current bra design, sizing, fitting and measurement concepts. It may be therefore suggested that the current anthropometric components of the traditional measurement method for a professional bra fit should be adapted to include correct fitting guidance.

Whilst fewer self-reported bra fit issues were reported after wearing the PFB, they were still identified within the bra fit assessment. The need to increase awareness and education around what correct bra fit looks and feels like is essential. Previous research suggests that educating adolescent girls via informative leaflets improves bra fit (McGhee et al., 2010), and further research could focus on implementing similar resources across a wide range of ages and breast sizes to address lack of education as a barrier to achieving correct bra fit.

### 4.2. Breast support

The design and fit of a bra has a direct impact on the external support it is able to provide for the breast (Zhou et al., 2013). Optimally, a bra would provide a natural uplift to the breast without compressing the soft tissue or causing bra-related discomfort (Zhou et al., 2013). An objective measure of breast uplift is NSN distance, which is a clinical measure frequently used during assessments of patients undergoing breast surgery (Scurr et al., 2015). Although NSN distance is a frequently used clinical measure, within research only two studies were found to report this measure during a static task (Scurr et al., 2015; Coltman, 2017), making inter-study comparisons difficult for this particular measure. Similarly, both studies reported nipple-to-sternal notch distance in a bare breasted condition, with participants completely undressed on the upper body and markers positioned directly on the nipple, rather than on the bra's material as performed in the present study.

Within the present study NSN distance was considered a valuable measure as an indicator of whether an uplift had been applied to the breasts when changing breast support garment. The professionally fitted bra immediately significantly reduced NSN distance compared to the usual bra, although at four weeks ($PFB_{28}$), the initial uplift provided by the professionally fitted bra was no longer evident, suggesting a gradual return towards a NSN distance comparable to the usual bra. Considering that this occurred after only a 4 week intervention period, this further calls into question the appropriateness of the recommendations to replace a bra after six to twelve months (North American Spine Society, 2007; Mercer, 2016; Isokariari, 2018). The range of mean NSN distances reported in this study (21.7 – 22. 3cm) are less than the smallest NSN distance reported in the Coltman et al (2017) study, where a breast with a volume of less than 499g and breast size 32DD/E, 34E, or 36DD. These breast sizes reported a NSN distance of 23cm in an unsupported condition. The largest breast size of 38H recorded a NSN distance of 33cm. Whilst the present study may have benefitted from an analysis of NSN distance in a bare breasted condition, it was perceived that this may have reduced likelihood of participation, and therefore it is difficult to compare between studies. The present study included a bra size range DD – HH and band size range 30 – 42 and the mean NSN distance for all participants was less than the NSN distance for the smallest group in Coltman et al's (2017) study, suggesting that the breast support garments counteracted any potential ptosis which may have been observed in a bare breasted position.

Whilst there are no previous studies to investigate the effects of a bra over an intervention period, the results from this study would suggest there is a need to consider the impact of bra care, age, wear and fabric deterioration on bra function. Alternatively, regular readjustment of the bra's adjustable components, such as bra strap length and / or the specific hook used to fasten the band may help to reduce some of these wear related factors.

When a combination of bra fit issues are present, the breast may be positioned uncomfortably within the bra cup. If, as seen in the usual bra, the band (50%) and straps (55%) are tight and the cups are small (41%) the compressive forces through the breast tissues onto the anterior chest wall may result in shortening of the NSN distance, but to the detriment of breast comfort and potential musculoskeletal pain. Therefore, if the introduction of the PFB could reduce the above-mentioned bra fit issues, it is possible that the NSN distance may increase to afford the decompression of breast tissue within the cup, which could be of benefit to the wearer.

Although the reported NSN changes reached statistical significance, an actual change of 0.6cm between the two conditions may be questioned for clinical relevance. For instance, simple adjustments to the bra straps may result in this change. Upon reflection it may have been beneficial to include a second bra fit assessment in the PFB after 4 weeks to assess any changes in bra fit quality over time in combination with change in objective measures of breast support. Within this study it was not possible to report whether the change in NSN distance had any clinical impact due to the healthy, asymptomatic characteristics of the participants, although this is something that could be explored in a clinical study, recruiting individuals with breast and/or bra related musculoskeletal pain.

### 4.3. Posture

Previously suggested underlying mechanisms for postural improvements suggest that a correctly fitted bra should open the chest, through retracted shoulders and reduced thoracic kyphosis (Coltman et al., 2013; Spencer and Briffa, 2013; Zhou et al., 2013; Odebiyi et al., 2015). In turn these adaptations may reduce resting tension through the scapular elevator and retractor muscles, and offload the anterior aspect of the intervertebral discs (Singla and Veqar, 2017). In the present study, improving initial bra fit quality in the professionally fitted bra resulted in immediate postural changes. At the upper thoracic region, movement towards extension was seen immediately, which would suggest that clinical postural benefits have initially been achieved. After 4 weeks however, this postural change was not maintained, as participants moved further into flexion than their initial posture recorded at baseline in the usual bra. This would suggest that change of breast support garment does not necessarily result in changes in spinal posture changes that would be considered clinically beneficial. In fact, the results would suggest the opposite, with participants adopting a more kyphotic standing posture after four weeks of wearing a professionally fitted bra when compared to their presenting posture in their Usual bra. However, other changes, such as changes in soft tissue resting length and tension may occur because of change in breast support garment, although these would not be evident in a biomechanical postural assessment. Soft tissue length and tone of the scapular elevators and retractors may alter at rest if the breast weight were better supported on the anterior chest wall, as measured through NSN distance. One potential limitation of gathering postural data for a group and measuring change is that the variance in posture between participants may cause oversight of actual postural changes. On reflection, the variety of different clinical postures that were assumed by participants could have been recorded at baseline, and then any change away from this posture could have been considered as beneficial or detrimental depending on the direction of change. Moreover, amongst a group of healthy participants, it may be argued that not one single posture was 'poor' or in need of correction due to the absence of any pain, as confirmed via pre-participation screening.

Many studies investigating the causal relationships between pain and posture often cannot indicate the cause; an individual will often only present for a clinical assessment upon the development on pain. At this point however, the body may already have adjusted in response to the presence of pain, and therefore it is unknown whether the posture the patient is presenting with is the cause of pain, or in fact a compensatory mechanical change due to the presence of pain (Laird et al., 2014).

Emerging research suggests that in a lot of cases where an individual presents with back pain, to suggest that their painful symptoms are associated to subtle variations in postural alignment is "medicalizing normality" (Lewis et al., 2020). The same author reports that, excluding extreme cases such as ankylosing spondylitis and severe kyphosis, the majority of postural abnormalities are just slight variations of "normal" posture and cannot differentiate between symptomatic and asymptomatic individuals (Lewis et al., 2020). Similarly, previous studies to investigate differences in spinal curvature and pelvic tilt between symptomatic patients and asymptomatic participants found no significant differences between the two groups (Laird et al., 2014), suggesting that there is no obvious difference in postural characteristics between those with and without pain. Perhaps defining posture as "good" or "poor" (American Academy of Orthopaedic Surgeons, 1947), "normal" or "abnormal" (Fortin et al., 2011), and "optimal" or "destructive" (Korakakis et al., 2019) may falsely imply that the differences between the two types of posture are explicit. Furthermore, defining posture as the pathological cause of pain may also be considered inaccurate when evidence suggests that there are no explicit postural differences between symptomatic and asymptomatic individuals (Laird et al., 2014).

In the present study, 50% of participants reported that they felt they had poor posture because of poor bra fit in the Usual bra, compared to 33% in the PFB, which shows a perceived postural improvement amongst participants due to changing breast support garment. Furthermore, 37% of participants experienced upper body muscle pain as a result of wearing the Usual bra, compared to 21% of participants in the PFB. A future clinical study, specifically recruiting individuals with back pain symptoms may provide significantly more valuable insight into the effects of different breast support garments on biomechanical postural change and associated impact on pain and discomfort.

### 4.4. Limitations

Whilst the application of a marker based camera system to collect kinematic data provided an in-depth analysis of both breast and spinal data, this approach may not be suitable for within many clinical environments, due to cost, space requirements and time burdens during set up. Future work may consider the application of inertial measurement units or electromagnetic tracking systems which may be more applicable clinically.

It may be argued that the application of markers to the surface of the bra measure the relative movement of the markers on the bra rather than the breast tissue encapsulated by the bra. Nonetheless, this approach is not a new concept within breast related research and has been used to measure breast kinematics for some time (Bridgman et al., 2010; Risius et al., 2014, 2017; McGhee and Steele, 2020b). It may also have been beneficial to include a bare breasted condition for each outcome measure to enable the measure of support to be measured compared to a baseline, but the research team believed this may have significantly influenced the likelihood of participation. This may be something to consider in the future.

## 5. CONCLUSION

This study explored the impact of three different breast support conditions, considering differences in bra fit quality and objective measures of breast support and postural characteristics. Whilst short-term intervention effects of a breast support garment have not previously been reported, this study suggests there is a need to further explore the impact of new breast support garments over time. The majority of breast support research has previously focused on support offered to the breasts by sports bras during physical activity, with very little consideration for the support offered to women by their everyday bra, during everyday activities. Due to the global trend of increasing breast size, research to address the problems associated with current bra design, sizing, fitting and measurement principles for larger breasted women is vital, to remove the barriers to achieving correct bra fit for all women, including education and awareness of what correct bra fit looks and feels like.

Although the research presented within this study recruited a healthy cohort, and can therefore can only make suggestions relating to the potential clinical impact of breast support garments, it sets the foundations for future work to investigate whether the implementation of better fitting breast support garments can influence musculoskeletal pain amongst larger breasted women, whilst attributing potential improvement of symptoms, objective measures of breast support and spinal posture.

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