Original Article

A NOVEL MULTI-STUDY INTERVENTION INVESTIGATING THE SHORT AND LONG TERM EFFECTS
OF A POSTURE BRA ON WHOLE BODY AND BREAST KINEMATICS

Melissa Jones, Chris Mills, Tim Exell and Joanna Wakefield-Scurr

School of Sport, Health and Exercise Science, Spinnaker Building, University of Portsmouth,
PO1 2ER.

Submitted to:	Gait & Posture
Date of Re-Submission:	October 2020
Abstract Word Count:	294 words (300 max)
Document Word Count:	3,488 words

Address for correspondence:

Dr Chris Mills

School of Sport, Health and Exercise Science

University of Portsmouth

Spinnaker Building

Portsmouth

PO1 2ER

United Kingdom

P: +44 (0) 2392 845294

Email: chris.mills@port.ac.uk

Abstract

Background:

Poor standing posture has been reported in women with larger breasts, increasing the risk of back pain. Whilst breast reduction surgery can improve posture, conservative measures such as special bras may offer short or long-term relief of symptoms without surgical intervention.

Research question:

This study aimed to utilise a multi-study intervention to investigate the short and long-term kinematic effects of wearing a posture bra.

Methods:

Study one utilised biomechanics and physiotherapy expertise to modify the design of a prototype bra to improve posture and breast kinematics; resulting in a second-generation posture bra. To test this bra, 24 females were randomly assigned to control and intervention groups. The control group wore their everyday bra; the intervention group wore the generation 2 posture bra in place of their everyday bra for three months. Pre and post intervention, posture (spine curvature, scapula position, whole body alignment) and breast kinematics were assessed during sitting, standing and walking. Short-term effects of the posture bra were compared to an everyday bra and no bra (study two), whilst the long-term effects were compared using the no bra condition (study three).

Results:

Biomechanical intervention improved posture and breast kinematics in a prototype posture bra resulting in a second-generation prototype. Pre-intervention, the generation 2 posture bra significantly improved scapula retraction by 6° during both sitting and standing, but also increased deviation of whole body alignment compared to everyday bra and no bra conditions. During walking the posture bra reduced breast motion by 17% compared to the

everyday bra. Following the three-month wearer intervention, scapula depression significantly improved in the intervention group.

Significance:

A biomechanically informed posture bra was able to effectively support the breasts and improve scapula position without compromising spinal curvature, reducing the risk of musculoskeletal pain associated with poor posture.

Keywords: spine curvature; prototype development; biomechanics; breast support

Highlights:

- A prototype development stage successfully informed subsequent posture bra design
- The generation 2 posture bra improved breast support compared to an everyday bra
- The generation 2 posture bra improved scapula retraction by 6°
- Following a wearer intervention scapula elevation was significantly reduced

Introduction

The female breast represents additional anterior load when compared to males. The average UK bra size is reported from 34D to 36DD [1] equating to a combined breast mass of over 1 kg [2]. The anterior mass of the breasts can cause negative symptoms including neck, back and shoulder pain; and restricted ability to exercise [3–5]. Poor standing posture, with increased levels of thoracic kyphosis and lumbar lordosis [4,6] has been previously linked with increased anterior load of larger (D cup) compared to smaller (A cup) breasts [6,7]. Furthermore, evidence suggests that sitting or standing for prolonged periods in poor postures such as increased thoracic kyphosis, lumbar lordosis and rounded shoulders might increase the risk of back pain and lumbar discomfort [8–10].

Whilst in extreme cases breast reduction surgery can improve posture [11], more conservative measures such as posture braces or specialised brassieres may offer relief of symptoms without the need for invasive surgery. Posture braces range from full back braces that target lumbar, thoracic and shoulder posture, to smaller braces, marketed to improve shoulder posture. These devices have been shown to help correct excessive shoulder protraction and increase shoulder muscle activity whilst being worn, improving both sitting and standing posture [12,13]. Further evidence suggests that these bracing devices are capable of improving shoulder function following a 6 to 12 week wearer intervention period [14], suggesting that such devices could act as a training aid, offering longer term benefits.

A small number of specialised brassieres designed with the aim of improving posture are commercially available [15]. These products are intended to replace the everyday bra, marketed as non-restrictive bras that can be worn all day under clothing to encourage

‘good’ or improved posture [15,16], however the efficacy of such products is yet to be investigated. The potential benefit of such posture bras is that they utilise an item of clothing commonly worn by females, and encourage better posture, which may reduce the risk of back pain without the need for additional devices. Whilst posture braces have been shown to affect sitting and standing posture in clinical populations, integrating key aspects of these designs into specialised bras may provide an insight into whether a posture bra could be a useful garment to aid postural improvements in women with larger breasts, thus acting as an alternative to invasive surgery or wearing an additional posture brace. Any posture bra designed to replace the wearer’s existing bra should maintain bra function by supporting the breasts; reducing breast motion during everyday activity, such as walking [17], whilst also encouraging posture correction. Whether an everyday or specialist posture bra, appropriate fit remains an important consideration as a poorly fitting bra may pull the upper thoracic region forward and down, hindering upper extremity motion and alignment [18]. This is emphasized further with Wood et al. finding women with a larger breast size tend to underestimate their bra size, hence possibly exaggerating the impact on posture [19].

Within functional and smart textile clothing development, multi-study programmes that evaluate product efficacy through development and evaluation stages have been effective in establishing appropriate products [20,21]. Such a research design can reduce the number of prototypes needed and provide a more robust product evaluation compared to only utilising final product evaluation. Although a small number of posture bras are commercially available, no evidence has been identified to support their development or outcome effects. The aims of this multi-study intervention were to utilise a combination of whole body and

breast kinematics to 1) inform the development of a posture bra, 2) evaluate the resulting bra as a posture-correcting device (short-term) and 3) a postural training aid (long-term).

The first study biomechanically informed the development of a new posture bra. Study 2 evaluated the short-term effects of wearing the posture bra during sitting and standing. Finally, following a three-month intervention, Study 3 evaluated the longer-term effects of wearing the posture bra during sitting and standing. It was hypothesised that: H₁: Biomechanical intervention will improve the ranking of the posture and kinematic benefits of a prototype posture bra; H₂: there will be significant improvement in posture when wearing the posture bra (short-term effect); H₃: during walking there will be no significant differences in resultant breast motion between the posture bra and everyday day bra, suggesting both bras provide equitable breast support and H₄: following the three-month intervention, once the posture bra is removed there will be significant improvements in posture, suggesting the posture bra is an effective training aid (long-term effect).

Methods

Following institutional ethical approval and informed consent, volunteers were recruited who were not pregnant, had not given birth or breast fed in the last year, had no previous breast surgery, were experiencing no injury, postural problems or back pain and were not undergoing any posture correcting intervention. Participants' bra size was established by a trained bra fitter, fitting in an everyday t-shirt bra (Marks & Spencer, London, UK), against a set of best-fit criteria [22].

Within each study, posture and breast motion were measured to assess the performance of each bra condition. Based on previous investigations into posture and clinical relevance, three measures of posture [23,24], whole body alignment, spine curvature and shoulder posture,

were assessed in studies 1, 2 and 3 (Figure 1). Whole body alignment during standing, was assessed using three-dimensional motion capture (240 Hz, Oqus, Qualisys, Sweden), with retroreflective markers bilaterally on the earlobe, glenohumeral joint centre, greater trochanter, lateral femoral condyle and lateral malleolus (Figure 2a) [24]. To assess spine curvature, electromagnetic sensors (240 Hz, Liberty, Polhemus, USA) were applied to the skin at the spinous processes at the first, fifth and tenth thoracic, third lumbar and second sacral vertebrae (T1, T5, T10, L3 and S2, respectively) to measure the thoracic, thoracic-lumbar and lumbar angle of the spine [23] (Figure 2b). Scapula retraction / protraction and elevation / depression were measured using electromagnetic sensors applied to both acromia and the sternal notch (Figure 2c). Resultant breast motion (left and right nipple) were measured, during studies 1 and 2 (Figure 1), using electromagnetic sensors and quantified relative to the torso using the T1, T10 and sternal notch electromagnetic sensors along with an additional sensor applied to the xiphoid process [25] .

===== INSERT FIGURE 1 HERE =====

===== INSERT FIGURE 2 HERE =====

For each study data were collected during 2-minute static trials both seated on a backless chair and standing, and during a 2-minute treadmill (H/P/Cosmos Mercury, Germany) walk at $5 \text{ km} \cdot \text{h}^{-1}$ [26].

To keep participants attention focussed forwards, they were instructed to watch a video on a television positioned directly in front them. No additional instructions for sitting or standing were given. Data collection was conducted in a secure room with a single female researcher

to ensure privacy and encourage natural posture. Measures of posture were recorded for 10 seconds during the static trials [10,27] and breast motion were recorded for 30 seconds during walking [28].

Study 1:

A pilot group of six females (mean (SD) age of 25 (3) years, height of 1.67 (0.06) m and body mass of 63 (6) kg) with a fitted UK bra size 34D were recruited. An initial prototype posture bra, produced by bra manufacturer Triumph International, was used as the base for developing a second-generation prototype. Existing posture devices, adapted physiotherapist recommendations on taping for posture [29], and the Research Group in Breast Health's knowledge of breast biomechanics and bra design [22,28,30,31], informed three new posture bra conditions (Figure 3). For each condition, kinesiology tape (PhysioRoom, UK) was applied to the initial prototype bra to increase tension on the garment, promoting good upper-body posture. Posture and breast motion data were collected in each taping condition, the original untapped prototype, and bare breasted (no bra). Conditions were ranked for each aspect of posture in descending order of deviation from the predefined ideal (defined in data processing and analysis section); these were then combined together to give overall posture ranking. Each condition was then ranked in descending order of breast motion; this was then combined with the posture rank to give an overall ranking. The highest ranked tape condition was then selected as the inspiration for the generation 2 posture bra; developed and produced by the manufacturer to replicate the concept provided by the tape.

===== INSERT FIGURE 3 HERE =====

Study 2:

Twenty-four females (age 25 (5) years, height 1.65 (0.05) m and mass 66 (7) kg) fitted as a UK bra size 34D were recruited. Posture and breast motion were assessed in three conditions: no bra, everyday bra (Marks & Spencer™ seam free plain underwired T-Shirt Bra, non-padded) and the generation 2 posture bra (Figure 2d). The everyday bra was selected as a low support bra, suitable for regular daily activities, similar to that used previously [30,31]

Study 3:

Data collected during study 2 were used as the pre-test for a three-month wearer intervention. Immediately following pre-test data collection, participants were randomly assigned to a control or intervention group using a combination of simple and block randomisation [32]. The control group were instructed to continue wearing their normal bra. The intervention group were provided with two generation 2 posture bras; instructions were provided and demonstration was given to show how the bra should fit. The bra was to be worn in place of their everyday bra for three months and adherence and bra comfort was monitored via a weekly questionnaire. After three months, all participants repeated the postural elements of the data collection in the no bra condition, to assess the posture bra's effectiveness as a training aid. Twenty-two of the 24 participants returned for the follow up testing (10 control, 12 intervention).

Data Processing and Analysis

During static trials, whole body alignment was analysed by reconstructing marker positions in Qualisys Track Manager (Version 2.13, Qualisys, Sweden) and exporting to MatLab (R2017a-2018a). Positional coordinates were rotated about the vertical axis of the global coordinate

system to align the left and right malleolus markers in the sagittal plane. All markers were projected onto the sagittal plane and vector angles calculated for shoulder (ear lobe, glenohumeral joint, greater trochanter), hip (glenohumeral joint, greater trochanter, lateral condyle) and knee (greater trochanter, lateral condyle, lateral malleolus). Ideal whole body alignment was represented by all segments aligning vertically [33]; therefore, the deviation from vertical was measured for each angle (Figure 2a) and summed to provide a deviation from whole body alignment angle.

For spinal alignment, data were exported to Visual3D (C-motion, USA); sagittal plane spine curvature angles were defined as the angle between T1, T5, T10 (thoracic); T5, T10, L3 (thoracic-lumbar) and T10, L3, S2 (lumbar) (Figure 2b). Angles were compared to previously reported 'ideal' spine curvature angles (thoracic = 19°, thoracic-lumbar = 3°, lumbar = -4°) [27] and absolute deviations from these were calculated.

Shoulder alignment was characterised by scapula retraction (+) / protraction (-) (transverse plane) and scapula elevation (+) / depression (-) (frontal plane), both represented by the angle between acromion and sternal notch markers (Figure 2c and 2d). Given a lack of reported ideal scapula position, scapula angles were normalised to participants' no bra, pre-test position to indicate whether there was a change relative to this baseline condition, representing altered posture. A positive change in scapula position was identified as reduction in protraction and elevation due to these being common deviations in posture associated with increased musculoskeletal pain [34–37].

In all conditions, breast motion during walking was calculated in three dimensions relative to the torso [25]. Nipple position data were filtered [38], then calculated relative to the torso local coordinate system (based on modified ISB recommendations [39] as the mid-point of the suprasternal notch and T1 markers, and the mid-point of the xiphoid process and T10 markers) [40]. Breast kinematics were reported as percentage reduction in resultant breast motion compared to no bra walking [17]. Gait cycles were identified using alternate inferior-superior minima positions of the suprasternal notch [41]; data were averaged for the middle 10 gait cycles.

Following tests for normality (Shapiro-Wilk tests, $P < 0.05$), a one-way repeated-measures analysis of variance (ANOVA) or Friedman test identified any short-term differences in posture and breast movement between bra conditions (study 2). Where significant within-participant effects occurred pairwise comparisons with Bonferroni correction detected where differences lay. Wilcoxon signed rank test was used to identify differences in breast support between the everyday bra and the generation 2 posture bra conditions. Within study 3, a two-way mixed ANOVA with one between-participant factor (group: control and intervention) and one within-participant factor (time point: pre and post) identified differences in posture during no bra sitting and standing.

Results

Study 1:

The addition of the tape to the original prototype improved posture and reduced breast motion. Tape condition three was ranked the highest of the taped bra designs (Table 1) and was used to inform the generation 2 posture bra (Figure 2d).

===== INSERT TABLE 1 HERE =====

Study 2:

Within the 24 participants tested, no statistically significant differences in thoracic or lumbar spine angles were observed between any breast support conditions during any activity (Table 2). Deviation from ideal thoracic-lumbar spine angle was significantly greater in the everyday bra during both sitting (11.3°) and standing (11.7°) compared to no bra (sitting $p = 0.036$, standing $p = 0.001$) and generation 2 posture bra (sitting $p = 0.001$, standing $p = 0.002$).

During both sitting and standing, the generation 2 posture bra resulted in significantly increased scapula retraction (6.1° and 5.9°) compared to no bra (sitting $p = 0.006$, standing $p = 0.006$) and everyday bra (sitting $p < 0.001$, standing $p < 0.001$) (Table 2). During standing, scapula protraction significantly increased in the everyday bra condition (-3.2°) compared to no bra ($p = 0.019$). Scapula elevation was significantly increased (sitting = 4.1° , standing = 3.8°), in the everyday bra condition compared to both no bra (sitting $p = 0.001$, standing $p = 0.001$) and the posture bra (sitting $p = 0.019$, standing $p = 0.001$) (Table 2).

Deviation from ideal whole body alignment was significantly greater in the posture bra ($<2^\circ$) compared to both the no bra ($p = 0.048$) and everyday bra ($p = 0.021$). During walking, percentage reductions in breast motion were significantly higher in the posture bra (73%) compared to the everyday bra (56%) ($p < 0.001$).

===== INSERT TABLE 2 HERE =====

Study 3:

During the 12 week wearer intervention the intervention group reported wearing the posture bra on average (SD) 5 (1.5) days a week for 8 (2.2) hours per day; no discomfort beyond what participants expected from an everyday bra was reported throughout the weekly written feedback. In no bra, there was no statistically significant change in any spine angles or scapula retraction ($p > 0.05$) pre to post intervention during either sitting or standing (Table 3). A significant decrease in scapula elevation was observed between the control (sit = 0.0° , stand = 2.7°) and intervention (sit = -2.1° , stand = -2.5°) group in both sitting ($p = 0.032$) and standing ($p = 0.035$) post intervention. In no bra, there was a significant improvement in whole body alignment from a pre intervention deviation of 10° to a post intervention deviation of 6° in both the control and intervention groups ($p < 0.001$).

===== INSERT TABLE 3 HERE =====

Discussion

In study 1, expertise in bra development, physiotherapy, and breast biomechanics combined to inform the development of a novel posture bra. All tape conditions were an improvement on the original prototype highlighting the benefit of this multidisciplinary approach to product development and accepting H_1 . The tape condition (3) that provided tension from the anterior shoulder to the thoracic spine, encouraging scapula retraction and depression; whilst providing tension to the lateral, superior and inferior borders of the breasts ranked highest and inspired the concept of the generation 2 posture bra.

Study 2 aimed to evaluate the short-term effects of wearing the generation 2 posture bra during sitting and standing. Thoracic-lumbar spine angle, scapula elevation and scapula protraction were improved when wearing the posture bra, partly accepting H₂. Breast motion was significantly lower in the posture bra compared to the everyday bra suggesting that the posture bra provided sufficient breast support for everyday activity, in excess of an everyday bra, rejecting H₃. Bras are generally designed to provide extrinsic support to the breasts, reducing the amount of breast movement, improving comfort and preventing breast pain[42]. Bras provide breast support by anchoring to other structures, such as the shoulders, through tension in the underband and shoulder straps [43]. In providing breast support, additional load can be applied to the shoulders and thoracic spine resulting in negative changes in postural alignment; such as increases in scapula protraction and thoracic-lumbar kyphosis seen in the everyday bra. However, the posture bra (generation 2) supported the breasts whilst maintaining / improving posture. The strap configuration, inspired by the prototype tape positioning, aimed to redistribute breast load and mimicked the tension applied in physiotherapy taping [29,44] to provide proprioceptive feedback, encouraging improved posture through scapula retraction and depression. These results suggest that unlike the everyday bra the generation 2 posture bra was able to provide support to the breast without negatively influencing posture. Small negative changes in posture such as those observed in the everyday bra, have been shown to alter muscle activity [45,46] and increase the risk of musculoskeletal pain [47].

Interestingly, scapula retraction increased in the generation 2 posture bra compared to no bra, whilst simultaneously, whole body alignment worsened in the posture bra compared to both the everyday bra and no bra conditions. Scapula protraction is often seen in combination

with an anterior head position [37]. The posture bra successfully improved scapula retraction, however no change in head position occurred in conjunction with this, therefore deviation from a vertical plumb line increased, hence worsening whole body alignment.

Using a three-month intervention, study 3 aimed to evaluate longer-term effects of wearing the posture bra during sitting and standing. Despite changes in spine curvature and scapula retraction whilst wearing the posture bra, no change was observed in the no bra condition (post intervention), rejecting H_4 and suggesting that the posture bra was not effective as a training aid. Any change in scapula retraction is likely due to the bra manipulating the position of the shoulders rather than due to a proprioceptive feedback response. In physiotherapy, taping can be applied to reduce tension when the segment is in the desired position; when the patient moves from this desired position, the tape develops tension stimulating a correction in posture, over time this movement pattern can become learned behaviour and continue without the stimulus [29]. The generation 2 posture bra design was unable to replicate a change in behaviour and therefore did not promote a long-term change in scapula retraction. Only two generation 2 bras could be provided to each participant in the intervention group due to manufacturing limitations and this may have affected adherence to wearing the bra, hence possibly reducing the potential for any long term posture changes.

A significant reduction in scapula elevation was reported post intervention in the no bra condition suggesting that the posture bra was successful in altering scapula elevation / depression beyond simply manipulating the position of the shoulders during wear. It is possible that the scapula retraction whilst wearing the bra, seen in study 2, resulted in increased activation of the latissimus dorsi and trapezius causing these muscles to strengthen

over three months [24]. The increased activation of these muscles, whilst not sufficient to produce a long term increase in scapula retraction may have caused the scapula depression observed [24]; however it will be necessary to measure the influence of the bra on muscle activity to investigate this further.

Significant improvement in whole body alignment was observed in both groups (control and intervention) following the three-month intervention period. As this improvement in posture was observed in both groups, the cause are factors other than the intervention. It is possible that on attending the second testing session, participants were aware of their posture being assessed. Despite measures to encourage a natural standing position, it is possible that knowledge of the study led to a bias in postural behaviour [23].

Biomechanical intervention was able to improve the posture and breast kinematics of a prototype posture bra, resulting in the development of a second-generation posture bra. Short term, the generation 2 posture bra improved breast support and scapula retraction compared to an everyday bra, but also increased deviation of the whole body alignment. Following a three-month intervention period, participants displayed increased scapula depression, suggesting the posture bra may have acted as a training aid to alter scapula elevation position long-term; however no changes in whole body alignment or spine curvature were observed. The short-term changes in scapula retraction seen in the posture bra were not maintained following the three-month intervention period. A biomechanically informed posture bra was able to effectively support the breasts and improve scapula position without compromising spinal alignment.

Conflict of interest statement

The authors have declared no conflicts of interest associated with this research.

Acknowledgements

The authors would like to thank Triumph International for providing the bras and funding this project, Kim Cessford for her guidance on physiotherapy for posture and the participants for taking part in the study.

References

- [1] T. Dove, Stretch to fit – made to fit†, *Int. J. Fash. Des. Technol. Educ.* 9 (2016) 115–129. <https://doi.org/10.1080/17543266.2016.1167252>.
- [2] A.J. Turner, D.G. Dujon, Predicting cup size after reduction mammoplasty, *Br. J. Plast. Surg.* 58 (2005) 290–298. <https://doi.org/10.1016/j.bjps.2004.11.008>.
- [3] P.L. Schnur, D.P. Schnur, P.M. Petty, T.J. Hanson, A.L. Weaver, Reduction mammoplasty: an outcome study., *Plast. Reconstr. Surg.* 100 (1997) 875–83. <http://www.ncbi.nlm.nih.gov/pubmed/9290655> (accessed March 18, 2019).
- [4] R. Goulart, D. Detanico Msc, R. Pires Vasconcellos Msc, G. Ricardo Schütz Msc, S. Giovana, S. Phd, Reduction mammoplasty improves body posture and decreases the perception of pain, *Can J Plast Surg.* 21 (2013) 29.
- [5] L. Spencer, K. Briffa, Breast size, thoracic kyphosis & thoracic spine pain - association & relevance of bra fitting in post-menopausal women: A correlational study, *Chiropr. Man. Ther.* 21 (2013) 1–8. <https://doi.org/10.1186/2045-709X-21-20>.
- [6] K. Findikcioglu, F. Findikcioglu, S. Ozmen, T. Guclu, The impact of breast size on the vertebral column: A radiologic study, *Aesthetic Plast. Surg.* 31 (2007) 23–27. <https://doi.org/10.1007/s00266-006-0178-5>.
- [7] A. Schinkel-Ivy, J.D.M. Drake, Breast size impacts spine motion and postural muscle activation, *J. Back Musculoskelet. Rehabil.* 29 (2016) 741–748. <https://doi.org/10.3233/BMR-160680>.
- [8] P. Waongenngarm, K. Areerak, P. Janwantanakul, The effects of breaks on low back pain, discomfort, and work productivity in office workers: A systematic review of randomized and non-randomized controlled trials, *Appl. Ergon.* 68 (2018) 230–239. <https://doi.org/10.1016/j.apergo.2017.12.003>.

- [9] P. Waongenngarm, B.S. Rajaratnam, P. Janwantanakul, Perceived body discomfort and trunk muscle activity in three prolonged sitting postures., *J. Phys. Ther. Sci.* 27 (2015) 2183–7. <https://doi.org/10.1589/jpts.27.2183>.
- [10] W. Dankaerts, P. O’Sullivan, A. Burnett, L. Straker, Differences in Sitting Postures are Associated With Nonspecific Chronic Low Back Pain Disorders When Patients Are Subclassified, *Spine (Phila. Pa. 1976)*. 31 (2006) 698–704.
<https://doi.org/10.1097/01.brs.0000202532.76925.d2>.
- [11] I. Sahin, S. Iskender, S. Ozturk, B. Balaban, S. Isik, Evaluation of Breast Reduction Surgery Effect on Body Posture and Gait Pattern Using Three-Dimensional Gait Analysis, *Aesthetic Plast. Surg.* 37 (2013) 549–553. <https://doi.org/10.1007/s00266-013-0102-8>.
- [12] A.K. Cole, M.L. McGrath, S.E. Harrington, D.A. Padua, T.J. Rucinski, W.E. Prentice, Scapular bracing and alteration of posture and muscle activity in overhead athletes with poor posture, *J. Athl. Train.* 48 (2013) 12–24. <https://doi.org/10.4085/1062-6050-48.1.13>.
- [13] J. Lee, H. Cynn, T. Yoon, C. Ko, W. Choi, S. Choi, B. Choi, The effect of scapular posterior tilt exercise , pectoralis minor stretching , and shoulder brace on scapular alignment and muscles activity in subjects with round-shoulder posture, *J. Electromyogr. Kinesiol.* 25 (2015) 107–114.
<https://doi.org/10.1016/j.jelekin.2014.10.010>.
- [14] M. Walther, A. Werner, T. Stahlschmidt, R. Woelfel, F. Gohlke, The subacromial impingement syndrome of the shoulder treated by conventional physiotherapy, self-training, and a shoulder brace: results of a prospective, randomized study., *J. Shoulder Elb. Surg.* 13 (2004) 417–23. <https://doi.org/10.1016/S1058274604000485>.

- [15] Leonisa - Posture corrector wireless back support bra, (n.d.).
<https://www.leonisa.com/uk/> (accessed January 23, 2020).
- [16] Intelliskin, IntelliSkin - Essential Bra, (n.d.).
<https://www.intelliskin.net/products/essential-bra-copy> (accessed August 4, 2020).
- [17] J.C. Scurr, J.L. White, W. Hedger, Supported and unsupported breast displacement in three dimensions across treadmill activity levels across treadmill activity levels, 29 (2011) 55–61. <https://doi.org/10.1080/02640414.2010.521944>.
- [18] A.R. Greenbaum, T. Heslop, J. Morris, K.W. Dunn, An investigation of the suitability of bra fit in women referred for reduction mammoplasty, *Br. J. Plast. Surg.* 56 (2003) 230–236. [https://doi.org/10.1016/S0007-1226\(03\)00122-X](https://doi.org/10.1016/S0007-1226(03)00122-X).
- [19] K. Wood, M. Cameron, K. Fitzgerald, Breast size, bra fit and thoracic pain in young women: a correlational study, *Chiropr. Osteopat.* 16 (2008) 1.
<https://doi.org/10.1186/1746-1340-16-1>.
- [20] K.E. Carroll, D.H. Kincade, Inclusive Design in Apparel Product Development for Working Women With Physical Disabilities, *Fam. Consum. Sci. Res. J.* 35 (2007) 289–315. <https://doi.org/10.1177/1077727X07299675>.
- [21] M. Suh, K. Carroll, N. Cassill, Critical Review on Smart Clothing Product Development, *J. Text. Apparel, Technol. Manag.* 6 (2010) 1–18.
- [22] J. White, J. Scurr, Evaluation of professional bra fitting criteria for bra selection and fitting in the UK, *Ergonomics.* 55 (2012) 704–711.
<https://doi.org/10.1080/00140139.2011.647096>.
- [23] A.P. Claus, J.A. Hides, G.L. Moseley, P.W. Hodges, Thoracic and lumbar posture behaviour in sitting tasks and standing: Progressing the biomechanics from observations to measurements, *Appl. Ergon.* 53 (2016) 161–168.

- <https://doi.org/10.1016/j.apergo.2015.09.006>.
- [24] F.P. Kendall, E.K. McCreary, P.G. Provance, *Muscles Testing and Function*, 4th ed., Williams and Wilkins, Baltimore, 1993.
 - [25] J. Scurr, J. White, W. Hedger, Breast displacement in three dimensions during the walking and running gait cycles, *J. Appl. Biomech.* 25 (2009) 322–329.
<https://doi.org/10.1177/0363546508314791>.
 - [26] J. Rose, J.G. Gamble, *Human walking*, Lippincott Williams & Wilkins, 2006.
 - [27] A.P. Claus, J.A. Hides, G.L. Moseley, P.W. Hodges, Is ‘ideal’ sitting posture real?: Measurement of spinal curves in four sitting postures, *Man. Ther.* 14 (2009) 404–408.
<https://doi.org/10.1016/j.math.2008.06.001>.
 - [28] S. Haake, J. Scurr, A dynamic model of the breast during exercise, *Sport. Eng.* 12 (2010) 189–197. <https://doi.org/10.1007/s12283-010-0046-z>.
 - [29] D. Morrissey, Proprioceptive shoulder taping, *J. Bodyw. Mov. Ther.* 4 (2000) 189–194.
 - [30] J.C. Scurr, J.L. White, W. Hedger, The effect of breast support on the kinematics of the breast during the running gait cycle, *J. Sports Sci.* 28 (2010) 1103–1109.
<https://doi.org/10.1080/02640414.2010.497542>.
 - [31] J. White, C. Mills, N. Ball, J. Scurr, The effect of breast support and breast pain on upper-extremity kinematics during running: Implications for females with large breasts, *J. Sports Sci.* 33 (2015) 2043–2050.
<https://doi.org/10.1080/02640414.2015.1026378>.
 - [32] K. Suresh, An overview of randomization techniques: An unbiased assessment of outcome in clinical research, *J. Hum. Reprod. Sci.* 4 (2011) 8.
<https://doi.org/10.4103/0974-1208.82352>.
 - [33] E.A. Ferreira, M. Duarte, E.P. Maldonado, A.A. Bersanetti, A.P. Marques, Quantitative

- assessment of postural alignment in young adults based on photographs of anterior, posterior, and lateral views, *J. Manipulative Physiol. Ther.* 34 (2011) 371–380.
<https://doi.org/10.1016/j.jmpt.2011.05.018>.
- [34] C.K. Wong, D. Coleman, V. diPersia, J. Song, D. Wright, The effects of manual treatment on rounded-shoulder posture, and associated muscle strength, *J. Bodyw. Mov. Ther.* 14 (2010) 326–333. <https://doi.org/10.1016/j.jbmt.2009.05.001>.
- [35] C.A. Thigpen, D.A. Padua, L.A. Michener, K. Guskiewicz, C. Giuliani, J.D. Keener, N. Stergiou, Head and shoulder posture affect scapular mechanics and muscle activity in overhead tasks, *J. Electromyogr. Kinesiol.* 20 (2010) 701–709.
<https://doi.org/10.1016/j.jelekin.2009.12.003>.
- [36] P.M. Ludewig, J.F. Reynolds, The association of scapular kinematics and glenohumeral joint pathologies, *J. Orthop. Sports Phys. Ther.* 39 (2009) 90–104.
<https://doi.org/10.2519/jospt.2009.2808>.
- [37] B.L. Braun, L.R. Amundson, Quantitative assessment of head and shoulder posture., *Arch. Phys. Med. Rehabil.* 70 (1989) 322–9.
<http://www.ncbi.nlm.nih.gov/pubmed/2930348>.
- [38] J.H. Challis, A procedure for the automatic determination of filter cutoff frequency for the processing of biomechanical data, *J. Appl. Biomech.* 15 (1999) 303–317.
<https://doi.org/10.1123/jab.15.3.303>.
- [39] G. Wu, F.C.T. van der Helm, H.E.J.D. Veeger, M. Makhsous, P. Van Roy, C. Anglin, J. Nagels, A.R. Karduna, K. McQuade, X. Wang, F.W. Werner, B. Buchholz, International Society of Biomechanics, ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand., *J. Biomech.* 38 (2005) 981–992.

- <http://www.ncbi.nlm.nih.gov/pubmed/15844264> (accessed March 18, 2019).
- [40] C. Mills, A. Loveridge, A. Milligan, J. Scurr, Trunk marker sets and the subsequent calculation of trunk and breast kinematics during treadmill running, *Text. Res. J.* 86 (2016). <https://doi.org/10.1177/0040517515609257>.
 - [41] W. Zijlstra, A.L. Hof, Assessment of spatio-temporal gait parameters from trunk accelerations during human walking., *Gait Posture.* 18 (2003) 1–10.
<http://www.ncbi.nlm.nih.gov/pubmed/14654202> (accessed March 18, 2019).
 - [42] B.R. Mason, K.A. Page, K. Fallon, An analysis of movement and discomfort of the female breast during exercise and the effects of breast support in three cases, *J. Sci. Med. Sport.* 2 (1999) 134–144. [https://doi.org/10.1016/S1440-2440\(99\)80193-5](https://doi.org/10.1016/S1440-2440(99)80193-5).
 - [43] K.-A. Page, J.R. Steele, Breast Motion and Sports Brassiere Design Implications for Future Research, *Sport. Med.* 27 (1999) 205–211.
<https://link.springer.com/content/pdf/10.2165%2F00007256-199927040-00001.pdf> (accessed July 18, 2018).
 - [44] R.M. Paine, M. Voight, The role of the scapula, *J. Orthop. Sports Phys. Ther.* 18 (1993) 386–391. <https://doi.org/10.2519/jospt.1993.18.1.386>.
 - [45] P.B. O 'Sullivan, W. Dankaerts, A.F. Burnett, G.T. Farrell, M. Ther, E. Jefford, M.M. Ther, C.S. Naylor, K.J. O 'sullivan, Effect of Different Upright Sitting Postures on Spinal-Pelvic Curvature and Trunk Muscle Activation in a Pain-Free Population The sedentary demands of modern life result in people spending more time sitting. 1 *Epidemiologic studies have, Spine (Phila. Pa. 1976).* 31 (2006) 707–712.
 - [46] A.P. Claus, J.A. Hides, G.L. Moseley, P.W. Hodges, Different ways to balance the spine: Subtle changes in sagittal spinal curves affect regional muscle activity, *Spine (Phila. Pa. 1976).* 34 (2009) 208–214. <https://doi.org/10.1097/BRS.0b013e3181908ead>.

- [47] E. Chaléat-Valayer, J.-M. Mac-Thiong, J. Paquet, E. Berthonnaud, F. Siani, P. Roussouly, Sagittal spino-pelvic alignment in chronic low back pain, *Eur. Spine J.* 20 (2011). <https://doi.org/10.1007/s00586-011-1931-2>.

Figure Captions:

Figure 1. Schematic overview of the multi-study development and assessment of a novel posture bra.

Figure 2. Measures of posture: sagittal plane whole body alignment (a), sagittal plane spine angles (b), coronal plane scapula elevation / depression (c) and transverse plane scapula retraction / protraction (d)

Figure 3. Kinesiological tape locations for tape conditions 1, 2 and 3 (a,b,c respectively) and the final (Generation 2) prototype (d)

Table 1. Mean (SD) angles of deviation (°) from vertical whole body alignment, ideal spine curvature, no bra scapula retraction and no bra scapula elevation, and breast motion reduction during study 1 (n=6).

		No Bra	Un-taped Posture Bra	Tape Condition 1	Tape Condition 2	Tape Condition 3
Sit	Deviation from ideal spine curvature (°)	5.4 (11.2)	7.4 (8.8)	5.0 (7.8)	3.9 (6.9)	3.6 (8.3)
	Scapula retraction (+)/protraction (-) (°)	/	9.7 (11.5)	12.8 (9.5)	12.8 (7.9)	13.5 (11.8)
	Scapula elevation (+)/depression (-) (°)	/	-0.5 (12.8)	-2.4 (11.8)	-1.0 (8.3)	-3.1 (11.7)
Stand	Deviation from vertical whole body alignment (°)	7.1 (4.3)	8.1 (4.5)	6.8 (3.6)	8.2 (4.7)	7.0 (3.2)
	Deviation from ideal spine curvature (°)	13.2 (8.4)	14.3 (7.1)	12.5 (6.0)	12.3 (6.0)	12.1 (5.0)
	Scapula retraction (+)/protraction (-) (°)	/	6.4 (10.7)	8.9 (11.8)	9.9 (10.9)	11.0 (9.9)
	Scapula elevation (+)/depression (-) (°)	/	-6.7 (7.1)	-3.4 (11.7)	-3.4 (10.9)	-3.2 (11.7)
Walk	Breast motion reduction (%)	/	63.9	66.6	69.5	69.3
Rank	Posture ¹	/	4 th	2 nd	3 rd	1 st
	Breast Support ²	/	4 th	3 rd	1 st	2 nd
	Overall ³	/	4th	3rd	2nd	1st

¹ Posture Score = (Sit (Scapula Retraction or protraction – Scapula Elevation or depression) – deviation from ideal spine) + (Stand (Scapula Retraction or protraction – Scapula Elevation or depression) – deviation from ideal spine – whole body alignment))

² Ranked according to greatest breast motion reduction

³ Ranked based upon equal weighting between posture and breast support rank.

Table 2. Mean (SD) angles of deviation (°) from vertical whole body alignment, ideal spine curvature, no bra scapula retraction and no bra scapula elevation during sitting and standing, and breast motion reduction during study 2 (n=24). * indicates significant within-participant effect.

		No Bra	Everyday Bra	Posture (Gen 2) Bra
Sit	Deviation from ideal thoracic spine curvature (°)	5.2 (4.2)	5.5 (6.0)	5.8 (4.4)
	Deviation from ideal thoracic-lumbar spine curvature (°)*	8.2 (4.8)	11.3 (4.7)	7.9 (3.8)
	Deviation from ideal lumbar spine curvature (°)	9.0 (6.1)	7.7 (5.5)	8.6 (5.5)
	Scapula retraction (+)/protraction (-) (°)*	/	-2.0 (4.7)	6.1 (6.2)
	Scapula elevation (+)/depression (-) (°)*	/	4.1 (4.9)	-0.3 (5.5)
Stand	Deviation from vertical whole body alignment (°)	10.2 (2.8)	9.3 (3.4)	11.1 (3.1)
	Deviation from ideal thoracic spine curvature (°)	4.0 (3.5)	3.7 (3.7)	4.1 (3.5)
	Deviation from ideal thoracic-lumbar spine curvature (°)*	8.4 (4.7)	11.7 (4.2)	8.4 (4.7)
	Deviation from ideal lumbar spine curvature (°)	22.6 (7.9)	23.3 (8.8)	22.6 (7.9)
	Scapula retraction (+)/protraction (-) *	/	-3.2 (5.1)	5.9 (7.7)
	Scapula elevation (+)/depression (-) *	/	3.8 (4.2)	0.7 (5.0)
Walk	Breast motion reduction (%)*	/	56 (18)	73 (12)

Table 3 Mean (SD) angles of deviation (°) from vertical whole body alignment, ideal spine curvature, no bra scapula retraction and no bra scapula elevation during sitting and standing in both control (n=10) and intervention (n=12) groups, pre and post the three-month posture bra intervention in a no bra condition. ^Δ indicates significant between group effects. * indicates significant within-participant effect.

		Pre		Post	
		Control	Intervention	Control	Intervention
Sit	Deviation from ideal thoracic spine curvature (°)	3.7 (3.7)	6.6 (4.3)	5.5 (3.3)	7.9 (5.2)
	Deviation from ideal thoracic-lumbar spine curvature (°)	8.4 (5.7)	8.1 (4.0)	4.6 (4.7)	8.4 (4.6)
	Deviation from ideal lumbar spine curvature (°)	9.2 (6.1)	8.8 (6.4)	5.8 (5.8)	10.8 (5.0)
	Scapula retraction (+)/protraction (-)	/	/	3.8 (6.1)	3.4 (11.2)
	Scapula elevation (+)/depression (-) ^Δ	/	/	2.7 (8.7)	-2.5 (5.4)
Stand	Deviation from vertical whole body alignment (°)*	10.4 (3.0)	10.1 (2.9)	5.5 (2.3)	6.2 (1.5)
	Deviation from ideal thoracic spine curvature (°)	2.8 (2.4)	5.1 (4.2)	3.8 (3.3)	4.1 (3.5)
	Deviation from ideal thoracic-lumbar spine curvature (°)	9.9 (4.8)	7.0 (4.3)	6.5 (4.7)	9.9 (11.6)
	Deviation from ideal lumbar spine curvature (°)	22.7 (10.2)	22.5 (5.0)	19.3 (10.5)	18.5 (8.0)
	Scapula retraction (+)/protraction (-)	/	/	-0.9 (3.9)	-3.0 (6.5)
	Scapula elevation (+)/depression (-) ^Δ	/	/	0.0 (4.6)	-2.1 (5.6)