THE EFFECT OF OPERATIONAL EQUIPMENT AND BRA TYPE INTERACTION ON BREAST BIOMECHANICS IN FEMALE POLICE OFFICERS

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The purpose of this study was to explore the interaction of different bra types with personal protective equipment (PPE) in female police officers. Breast motion of 13 officers was recorded in low, medium and high bra support conditions during jogging. Displacement (m) of different locations of breast tissue were recorded and compared. The high support condition, with the addition of PPE, significantly reduced breast motion. PPE reduced breast movement suggesting increased compression from body armour and tactical vest. Results suggest officers should consider a high support bra for wear during work shifts as occupational performance may be compromised by breast support.

KEYWORDS: Breast Support, Females, Occupational Health, Bra.

INTRODUCTION: No biomechanical research has investigated the interaction between bras and personal protective equipment (PPE), despite the requirement of PPE (body armour and tactical vest) to be worn by female police officers whilst on long-duration shifts (Pyke et al., 2015). Due to the historical gender dominance within physically demanding occupations, PPE was designed to fit male anthropometrics (Coltman et al., 2020). Fit may be altered by differing manufacturer, style and materials due to each police force independently issuing PPE (Malbon et al., 2020). Fourty-two percent of police recruits are represented by females, with increasing numbers (GOV, 2022). Female officers need to experience both physical and psychological comfort when wearing body armour, avoiding any effect on performance (Niemczyk et al., 2017). A high incidence of breast and bra issues, across bra types, have been reported in other active populations, such as equestrians and army recruits (Burbage & Cameron, 2018; Burbage et al., 2021). Issues include rubbing, chaffing, excessive breast motion and poor posture (Burbage et al., 2021). Sixty-seven percent of female officers report wearing a bra with body armour to be uncomfortable, regardless of bra type (Malbon et al., 2020). Body armour has been altered slightly to better suit bust-like shapes, however, this is limited to layering, stitching, tapering and folding materials (Malbon et al., 2020). The bust shape of the encapsulated soft tissue can be altered dependent on bra type, which includes compression, encapsulation and underwired styles (Niemczyk et al., 2017). Altered bust shape could add to discomfort of body armour fit, which is critical to avoid to reduce negative effects on human performance (Coltman et al., 2021; Coltman et al., 2020; Malbon et al., 2020). Despite knowledge of the benefits of sports bra wear for reducing breast pain and motion, only 17% of female officers choose to wear a sports bra on shift (Malbon et al., 2020). However, the suitability of a sports bra for long duration wear and occupational tasks is unknown. Seventy-seven percent of female police officers wearing underwire bras have been found to be wearing the wrong size bra following professional fitting, highlighting further health and support issues (Malbon et al., 2021). The aim of this study was to explore any differences in breast motion, which exist across bra types, with the addition of PPE. It was hypothesised that as breast support with and/or without PPE increased, breast motion reduced.

METHODS: Following institutional ethical approval, 13 female British Police officers (Age 30.1 ± 6.1 years, Mass 67.1 ± 10.4 kg, Height 1.65 ± 0.8 m) volunteered and participated. Participants had a self-reported bra band size range of 32-38 inches and a bra cup size range of B-E, were currently free from injury and undertaking at least 150 or 70 minutes of moderate or vigorous intensity exercise weekly, respectively. Professional bra fitting criteria (White & Scurr, 2012) was used to size and fit an everyday underwired (seam free plain underwired T-

Shirt Bra, non-padded; Marks & Spencer™) (Underwired), compression (Action or Super Sports Bra; Sportjock™, Derby, UK) (Compression) and padded combination (combination of compression and encapsulation) (Padded Run Bra; Shock Absorber™, Gossard, UK) (Combination) bra prior to trials. Eight lightweight electromagnetic sensors and a six-degrees of freedom motion sensor system (240 Hz, Liberty Micro Sensor 1.8, Polhemus, USA; outer diameter, 1.8mm; mass < 1 g) were used to quantify vertical displacement of breast tissue. Sensors were placed on the suprasternal notch, xiphoid process, C7, T8, left nipple, and the most lateral, medial and upper boundaries of breast tissue (Figure 1A) (Norris et al., 2020). Participants carried out an individualised warm-up, familiarising themselves with the motorised treadmill (Sole Fitness F80 folding treadmill, Sole Fitness, Utah, US) followed by a static trial and six 60 second jogs at a self-selected pace (>7 km/h) (7 – 8.5 km/h). The pace remained the same across conditions and was decided in a non-PPE condition. Jogs consisted of one trial in each bra condition, with and without PPE (Underwired, Underwired PPE, Compression, Compression PPE, Combination, Combination PPE), in a randomised order. Armour and vests were fitted as per manufacturer guidelines and loaded using customised sandbags (Figure 1B). Data were captured for the final 30 seconds of each trial. During rest periods, a questionnaire was conducted to evaluate comfort, pain and any bra issues during trials.

A.

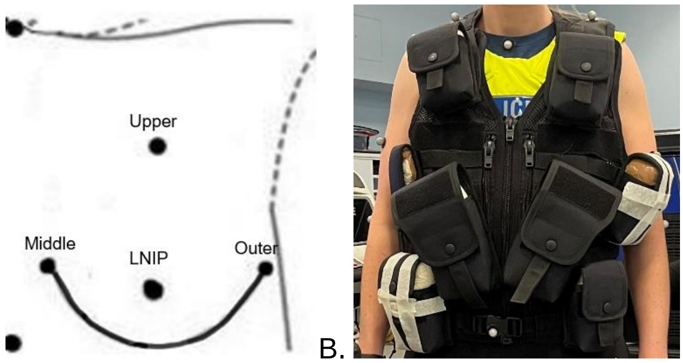

Figure 1. A. Breast Sensor-array (black circles) configuration. Demonstrated on left breast. Adapted from Norris et al. (2020). B. MOLLE pouch arrangement on tactical vest, on top of participants own body armour.

Breast positional data were exported into Visual 3D (C-Motion, Boyds, MD), filtered using a second order low-pass Butterworth filter, with a 13 HZ cut-off frequency (Mills et al., 2015). Breast markers were transformed, and computed in relation to the thorax segment. Five gait cycles per trial were analysed using custom written code in MATLAB (R2022a, MathWorks Inc., Natick, MA, USA). Individualised gaits were time normalised to 101 data points. The sternum marker was used to define the gait cycle. Touchdown was marked as the point when marker velocity changed from positive to negative. IBM SPSS statistics (SPSS, v25, IBM Corp, Chicago, IL, USA) was used for statistical analysis. A Shapiro-Wilk's test was used to confirm normality. Two-way repeated measures ANOVAS were used to assess any changes in breast motion across conditions, with Tukey post-hoc tests to compare differences, with an alpha priori level of 0.05.

RESULTS: Significant interaction effects were found between conditions ($p < .05$). Post-hoc testing found the vertical range of motion in breast displacement showed significant differences between underwired and other conditions for the left nipple, across five strides. Magnitude of vertical breast displacement was smaller in combination PPE in comparison to all other conditions (Table 1). Mean comfort level (1-10) for the combination PPE (8.23) was higher compared to underwire PPE (5.42) and compression PPE (6.33). When averaged across the five strides, vertical displacement in the high breast support condition was shown to reduce with the addition of PPE (0.022 m compared to 0.017 m).

Table 1: Average vertical range of motion, from all 13 participants across five gait cycles.

	Sensor (m)			
Condition	**LNIP**	**Middle**	**Outer**	**Upper**
Combination	0.0221□	0.0205	0.0238	0.0222
Combination PPE	0.0177┘ □	0.0175	0.0191□	0.0170
Compression	0.0281☼	0.0233	0.0257	0.0225
Compression PPE	0.0198□	0.0186	0.022□	0.0182
Underwired	0.0332▪☼◊*	0.0221	0.0282☼◊	0.0258
Underwired PPE	0.0219□	0.0191	0.0253	0.0216

▪significantly different to combination, ☼significantly different to combination PPE, ┘significantly different to compression, ◊significantly different to compression PPE, □significantly different to underwire, *significantly different to underwire PPE = $p < .05$.

Left nipple was shown to have the greatest change in vertical range of motion, compared to sensors at the outer, middle and upper boundaries of the breast tissue. Vertical displacement peaked for the left nipple during transition from stance to swing (Figure 2).

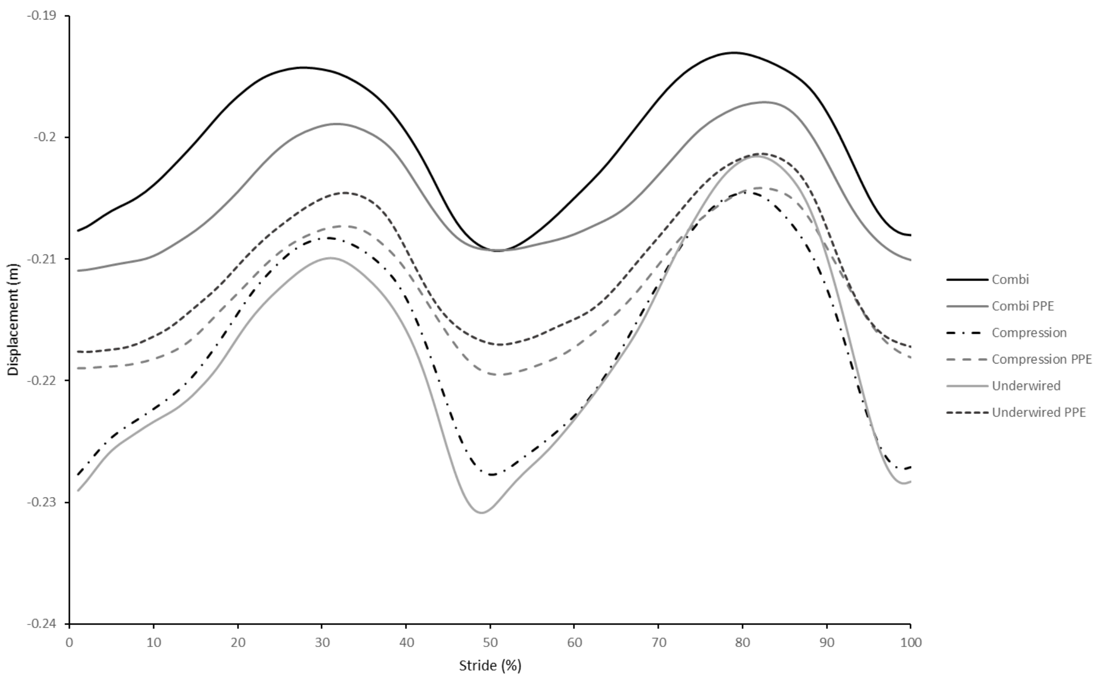

Figure 2: Vertical displacement (m) of left nipple across one stride, for all conditions starting at right heel strike.

DISCUSSION: This is the first study, to the authors' knowledge, to quantify breast displacement during treadmill running with the addition of personal protective equipment. This research continues to support previous publications in the area, in which high breast support continues to be the greatest recommendation for activity (White et al., 2015). This is due to the reduction in breast motion as support increased. Thus, supporting the hypothesis of this study. Moreover, the addition of PPE suggests an additional level of compression to the breast tissue, reducing breast displacement further. Results provide evidence of significant differences between bra types. However, older and larger-breasted officers were excluded due to the effect of breast age and size on breast biomechanics; therefore, sample size could have been improved for greater application to the population.

Initial breast movement can be seen to begin at different points, once averaged for each trial (Figure 2). This is due to independent locations of sensors in relation to the thorax. Different bra styles compress breast tissue in uncommon ways, therefore, breast tissue may start in non-identical positions. Thus, range of motion during oscillations of the gait cycles were investigated for each condition (Table 1).

Reduction in the range of motion of breast tissue as bra support increases remains in line with previous publications (e.g. White et al., 2015). A high support bra significantly reduced breast kinematics, leading to reduced breast pain ($p < .05$). Positive correlations have been shown between peak breast ROM and breast pain, proposing as motion increases, breast pain increases (Scurr et al., 2010). Thus, if breast motion reduces within the high support sports bra under PPE, there may be the need to consider future recommendations of a high support sports bra for police officers on shift. This could lead to enhanced physical and psychological comfort, therefore, leading to improved performance (Niemczyk et al., 2017).

Recommendation of high support bra wear under PPE, due to reduction in breast displacement, has future implications. The effects of long duration wear of a high support sports bra (for example, a combination bra), is unknown, particularly with the addition of PPE for police officers for a whole shift. Therefore, comfort alongside support should be key focus for any future design, recommendation or product development.

CONCLUSION: This study was the first to identify whether varying levels of breast support underneath PPE, for female police officers, altered breast biomechanics. During running, the greatest ROM at the nipple was found for an underwire bra. In comparison, a high-level support bra underneath PPE showed the smallest range of motion for the nipple. The combination bra also aligned with the highest comfort level. With the addition of further analysis, quantification of breast motion underneath PPE will improve recommendations on suitable bra type for female police officers on shift.

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