EVALUATING THE EFFECTIVENESS OF SPORTS BRAS DURING TREADMILL RUNNING THROUGH DISCRETE AND CONTINUOUS MEASURES OF BREAST KINEMATICS

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This study aimed to compare discrete and continuous breast kinematics and assess their relationship with perceived breast pain and support. Breast motion was assessed as relative nipple position, velocity and acceleration for 36 females during treadmill running. Statistical parametric mapping identified where and for how long across the gait cycle sports bras were effective at reducing breast movement. Superior-inferior range of motion (r=0.86) was most closely associated with perceived breast support; breast pain was most closely associated with anterior-posterior peak (-) acceleration (r=0.7). Continuous analysis of breast movement can identify when in a gait cycle breast movement significantly differs between breast support conditions. Discrete measures are more discernible at identifying what variables contribute to feelings of breast pain and support.

KEYWORDS: breast. kinematics, SPM, sports bras, pain

INTRODUCTION: The majority of breast biomechanics research has investigated the displacement of the nipple during various dynamic activities, however, it is largely focused on discrete measures. Changes in breast support conditions assessed from peak values or a change in magnitude only provides an indication of what is happening at discrete time points, rather than understanding continuous effects across the gait cycle. It has been reported that consumers are unable to perceive the level of support provided by a sports bra when comparing perceived ratings of support with discrete measures (Renwick et al., 2023). Time histories for breast movement have previously been qualitatively assessed but have not been quantified. Evaluating breast movement continuously across the gait cycle may help to identify areas where certain bra designs are more or less effective at reducing breast kinematics, which may more closely correlate with changes in perceived breast pain and support. It may be that some sports bras are effective over a greater proportion of the gait cycle, but the magnitude of their effect is less. Additionally, nipple position has been reported as varying between individuals (Coltman et al., 2022) however it is unclear what influence this variation may have on continuous measures of breast displacement. In the wider biomechanics literature, statistical parametric mapping (SPM) (Pataky, 2010) has become an increasingly popular method for time-continuous variables to be compared and may be a useful analysis tool for testing the effectiveness of sports bra designs through the assessment of breast motion. The aim of this study was to compare discrete and continuous breast kinematic variables and to assess their relationship with perceived breast pain and support.

METHODS: Following institutional approval (SHFEC 2019-031B), 36 females (mode bra size 34D: under-bust 76.3 cm (2.5); over-bust 92.2 cm (4.6); mass 66.7 kg (5.8); aged 19-39 years) gave written informed consent to participate. Participants had their bra fit assessed in a medium size sports bra (Nike Flyknit Sports Bra) by a trained bra fitter using professional-fit criteria (McGhee & Steele, 2010). To measure nipple movement, nipple and torso positional data were captured at 240 Hz using an electromagnetic sensor system (Liberty Micro Sensor 1.8, Polhemus, USA; outer diameter, 1.8 mm; mass, ≤1.0 g). Sensors were attached to the suprasternal notch (STN), xiphoid process, 7th cervical vertebra, 8th thoracic vertebra and left nipple (Mills et al., 2016). Participants ran on a treadmill at 10 kmph, for 40 seconds and sensor positional data was recorded during a bare-breasted and a sports bra run (Nike Flyknit Sports Bra). After each run, participants rated on a 0 to 10 scale perceived breast pain (0 = no pain, 10 = severe pain) and support (0 = very unsupportive, 10 = very supportive).

Motion sensor data were processed in Visual3D (version 6, C-Motion, Inc., Germantown, USA). Left nipple motion was calculated relative to the torso reference system. Gait cycles were identified from right foot contact to right foot contact using every other inferior minima of STN (Norris et al., 2019) and the maximum mediolateral position of STN to distinguish right or left step (Reeves et al., 2022). Breast displacement was the range of motion (ROM) and the instantaneous peak maximum and minimum values; breast movement reduction from bare-breasted to sports bra condition was also reported as the percentage reduction in ROM (Norris et al., 2021). Breast velocity and acceleration were calculated as the instantaneous first and second derivatives of left nipple position and were reported as peak instantaneous values; all discrete values were calculated over ten gait cycles and then averaged. Discrete data were checked for normality using Shapiro-Wilk tests; not all data were normally distributed therefore were compared between breast support conditions using either a Wilcoxon signed-rank or a paired samples t-test.
Time histories for relative left nipple position, velocity and acceleration in each direction across ten gait cycles were averaged for each participant and then compared across the two breast support conditions using one-dimensional SPM (Pataky, 2010) using paired t-tests to identify differences between breast support conditions. The criterion alpha level was 0.05. As non-normalised displacement does not account for individual differences in nipple position between participants, time series data for nipple position was normalised by subtracting the mean value in each gait cycle from every timepoint in the series to investigate how this may affect continuous measures of breast displacement. The duration of the gait cycle (%) and area between the curves (unit/% gait cycle) where there was statistical difference between support conditions was summed for each participant. Spearman's rho correlation coefficients were used to assess the relationship between breast pain and support with discrete variables for minimum, maximum and ROM for displacement, peak instantaneous values for velocity and acceleration, breast movement reduction (%) and peaks; and with continuous variables for the duration of the gait cycle (%) and the area between the curves (unit/% gait cycle) where there was statistical difference between support conditions.

RESULTS: Discrete measures of nipple displacement, velocity and acceleration were significantly reduced in the sports bra compared to the bare-breasted condition for all variables except peak lateral displacement (p=0.156) (Table 1). Breast movement reduction %(SD) was: 52% (18) for AP, 78% (9) for ML and 59% (10) for SI directions. Median scores for perceived breast pain were 5 and 0 for bare-breasted and bra condition respectively. Median score for breast support in the bra condition was 8.

Table 1: Mean (standard deviation) relative nipple displacement (m) range of motion (ROM), maximum (+) and minimum (-) breast position (m), peak relative breast velocities (m/s) and accelerations (m/s^2) in anterior-posterior, medial-lateral and superior-inferior directions during 10 kmph treadmill run in bare-breasted and sports bra conditions for N=36. P-value reports statistical comparison between bra and no bra conditions. *indicates Wilcoxon signed-rank tests.

		Displacement (m)			Velocity (m/s)			Acceleration (m/s^2)		
		Bare-breasted	Sports bra	p-value	Bare-breasted	Sports bra	p-value	Bare-breasted	Sports bra	p-value
Anterior-posterior	Anteroposterior ROM	0.028 (0.01)	0.01 (0)	<0.001*						
	Peak anterior (+)	0.152(0.01)	0.13 (0.01)	<0.001	0.31 (0.08)	0.20 (0.06)	<0.001	25.2 (10)	6.9 (2)	<0.001
	Peak posterior (-)	0.124 (0.01)	0.12 (0.01)	0.015	-0.50 (0.21)	-0.16 (0.06)	<0.001*	-24.9 (9)	-10.8 (4)	<0.001*
Medial-lateral	Mediolateral ROM	0.04 (0.01	0.01 (0)	<0.001						
	Peak medial (+)	0.125 (0.01)	0.09 (0.03)	<0.001	0.51 (0.18)	0.10 (0.03)	<0.001*	23.8 (8)	5.2 (2)	<0.001
	Peak lateral (-)	0.085 (0.01)	0.08 (0.03)	0.156	-0.49 (0.25)	-0.08 (0.03)	<0.001*	-19.0 (8)	-4.6 (2)	<0.001
Superior-inferior	Superior-inferior ROM	0.080 (0.02)	0.03 (0.01)	<0.001						
	Peak superior (+)	-0.151 (0.01)	-0.17 (0.02)	<0.001	0.61 (0.27)	0.27 (0.10)	<0.001*	54.0 (14)	20.8 (6)	<0.001
	Peak inferior (-)	-0.231 (0.02)	-0.20 (0.02)	<0.001	-1.33 (0.34)	-0.47 (0.12)	<0.001	-27.0 (7)	-11.4 (3)	<0.001

Figure 1 displays the mean (SD) time series data with highlighted time intervals where relative breast kinematics were significantly different between bare-breasted and sports bra running.

In the AP direction, displacement was significantly reduced in the sports bra condition at three time intervals; mediolaterally displacement was significantly reduced in the bra condition at two time intervals; and in the SI direction displacement was significantly reduced at five time intervals. When displacement was normalised, the duration of significant time intervals increased. Velocity was significantly reduced when running in the bra compared to no bra, with the greatest difference recorded in the SI direction. Across all directions, acceleration saw the greatest number of time intervals of significant difference between support conditions but they were shorter in duration. Area between the curve was greatest in the SI direction for non-normalised (0.2m/%gait cycle) and normalised displacement (0.2m/%gait cycle); velocity (3.5m/s/%gait cycle) and acceleration (135m/s^2/% gait cycle). Out of the 36 variables analysed, a strong relationship with perceived support (r=>0.5) was reported for 19 variables with the strongest relationship reported for the discrete variable SI ROM (r=0.857; p=<0.001). Strong relationships with breast pain were reported for 18 variables with the strongest relationship reported for AP peak (-) acceleration (r=0.715; p=<0.001).

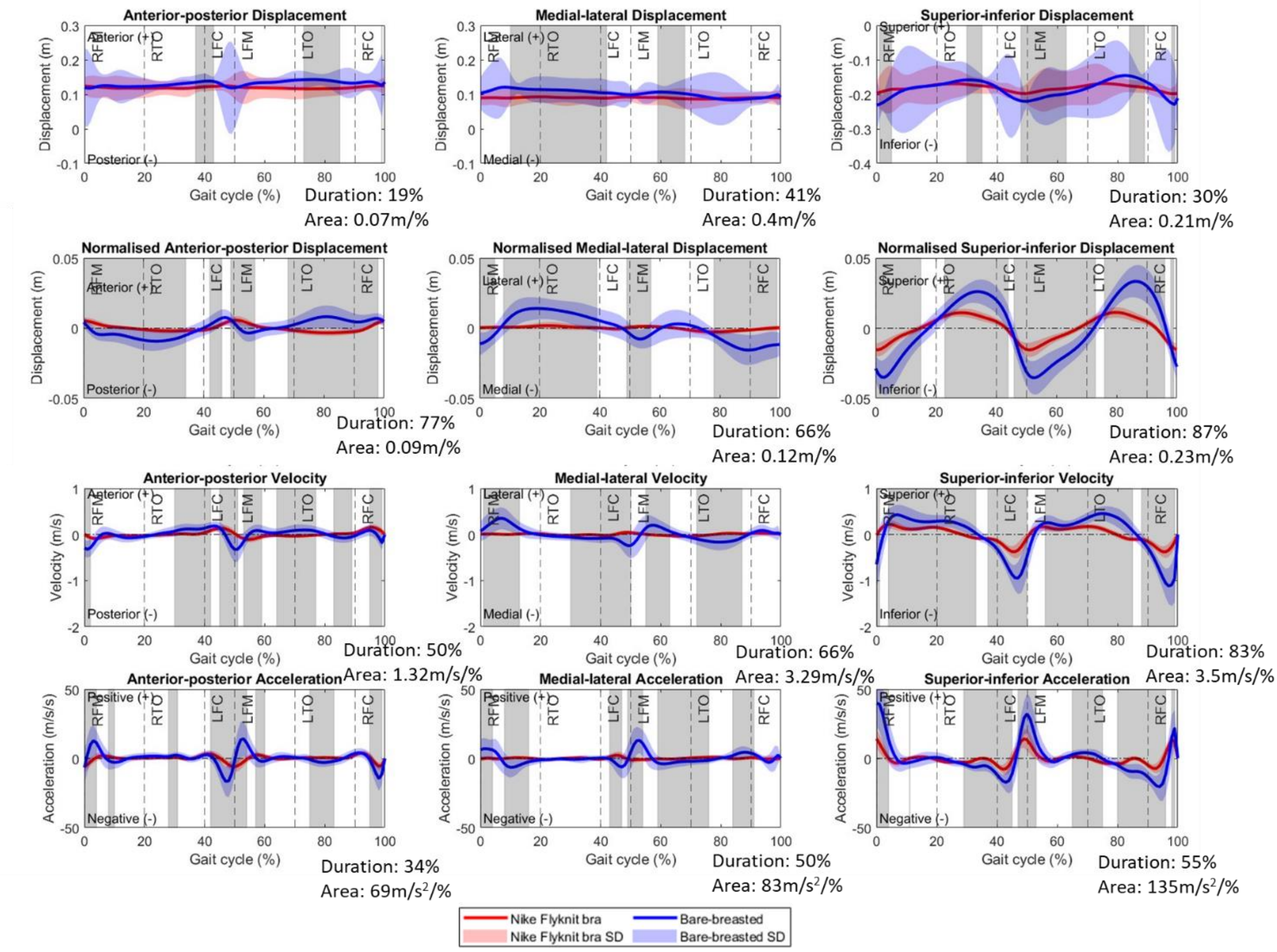

Figure 1: Statistical parametric mapping of mean (standard deviation) relative left nipple displacement, velocity and acceleration in anterior-posterior, medial-lateral and superior-inferior directions across the gait cycle. Mean (SD) of ten gait cycles for N=36. Vertical shaded bands highlight time intervals of statistical difference (p=<0.05) between bare-breasted and sports bra during treadmill running at 10 kph. Total duration refers to the total time (% of gait cycle) of statistical difference. (RFC=right foot contact, RFM= right foot midstance, RTO = right toe-off, LFC=left foot contact, LFM=left foot midstance, LTO=left toe-off).

DISCUSSION: Breast kinematics were reduced in the sports bra condition for all discrete variables, in all directions except for peak lateral displacement. Analysis of continuous measures of breast kinematics using SPM identified multiple points across the gait cycle where the sports bra significantly reduced breast movement. Peaks of SI normalised displacement were reduced in magnitude when the nipple was at its most superior and inferior positions which suggests the bra is working at the extremes of breast displacement which might have material implications for sports bra designs. Nipple acceleration was reduced for a similar duration of the gait cycle in the SI and ML directions however they differed substantially for the area between the curves measure suggesting that the sports bra is more effective at reducing magnitude of acceleration in the SI direction; evaluation of duration and magnitude of change between breast support conditions using SPM could distinguish between bra designs which are more suited to reducing breast motion during different activities. Non-normalised displacement had the shortest duration of significant difference between bare-breasted and bra condition; when displacement was normalised, the duration of time spent significantly reduced increased for each direction. Normalising displacement reduces the variance in displacement measures related to individual differences in the distance between the nipple and sternal notch therefore it is recommended that continuous measures of breast displacement use normalised time series data. Velocity and acceleration were reduced for multiple time points across the gait cycle in each direction, however, excluding SI velocity, the duration of time across the gait cycle where these variables were reduced was less than normalised displacement which indicates that the sports bra was less effective at controlling and reducing the speed of breast movement. Breast movement reduction (%) is used as a surrogate measure for breast support (Norris et al., 2021), however, in all directions correlations with perceived breast support were weak which is in agreement with Renwick et al., (2023). For both perceived breast pain and support, correlations with discrete measures were stronger than those with continuous measures. This suggests that continuous analysis of breast movement is useful for identifying when in a gait cycle breast kinematics significantly differ between breast support conditions but discrete measures are more discernible at identifying what variables contribute to feelings of support and pain.

CONCLUSION: Statistical parametric mapping identified when during the gait cycle sports bras are working to reduce breast movement and could be used as a tool to test the effectiveness of activity specific sports bra designs. Discrete SI ROM had the strongest relationship with perceived breast support and AP peak (-) acceleration had the strongest relationship with perceived breast pain. Discrete measures of breast kinematics had a stronger relationship to feelings of breast pain and support compared to continuous measures.

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