MAGNITUDE OF MULTIPLANAR BREAST KINEMATICS DIFFERS DEPENDING UPON RUN DISTANCE

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ABSTRACT

Recommendations for breast support, dynamic breast pain assessment, and implications for sports performance have been made within breast biomechanics research; however, these studies have been based upon short exercise protocols (2 to 5 min). The aim of this study was to investigate the effect of breast support on multiplanar breast kinematics over a five kilometre run. Ten female participants (34D or 32DD) conducted two five kilometre runs, in a low and high breast support. Relative multiplanar breast kinematics were averaged over five gait cycles at six intervals of a five kilometre run. Increases in multiplanar breast kinematics were reported from the start to the end of the run, with the greatest rate of increase in breast kinematics reported within the first two kilometres of running. The greatest relative increases in breast range of motion (34%), velocity (33%), and acceleration (41%) were reported in the superioinferior direction at the fifth kilometre (33 minutes of running) in the high breast support. Key findings suggest that the run distance, and therefore run duration, employed for both fundamental research and product validation protocols should be carefully considered and it is suggested that running protocols for assessing breast biomechanics should exceed seven minutes.

Key words: *Running, sports bras, breast support, females, kinematic*

INTRODUCTION

The majority of literature investigating the biomechanics of the breast has been conducted during treadmill running (Mason, Page, & Fallon, 1999; McGhee, Steele, Power, 2007; Scurr, White, & Hedger, 2009; 2010; 2011). From this research sports bras are recommended as the most appropriate breast support for females, based upon the reduction of relative breast kinematics (Mason et al., 1999; Scurr et al., 2009), improvements in breast comfort (McGhee et al., 2007; Scurr et al., 2010), and the potential to widen exercise participation (Mason et al., 1999). Important research areas are examined in these publications, such as establishing what an effective breast support is, which informs product design (Starr et al., 2005), the assessment of breast pain, ensuring females are exercising in comfort (Scurr, et al., 2010), and examining functional alterations during running to examine the effect of breast biomechanics on sports performance (Boschma, Smith, & Lawson, 1995; White, Scurr, & Smith, 2009).

While these publications have significantly progressed knowledge within the area of breast biomechanics, the conclusions drawn have been the result of work conducted over short running bouts (up to 5 minutes). Many modalities of exercise, specifically running, are often conducted over durations exceeding two minutes. Furthermore, the current UK government guidelines on exercise prescription to maintain a healthy lifestyle for adults is thirty minutes of exercise (the equivalent of a five kilometre run paced at 10 km.h^{-1}) five times a week (Department of Health, UK, Physical activity recommendations, 2011). Previous literature has not considered the magnitude of breast kinematics over common running distances, which limits the possible application of the results.

To date, one publication has monitored breast displacement at minute intervals over a five minute treadmill run, to explore the notion that poor breast support (everyday bra) may pose an injury risk to the breast. Bowles and Steele (2003) reported significant increases in superioinferior breast displacement from the first minute to the fourth and fifth minute of running. Bowles and Steele (2003) attributed increases in breast displacement to tissue strain as a result of the repeated loading on the delicate breast tissues during running. However, it is extremely difficult to isolate tissue strain when wearing an external breast support, as it is unclear if the support is influencing the magnitude of breast movement. It could be hypothesised that the loading on the breast tissue over an extended run (e.g. five kilometre run), and therefore the support demand on the bra, is much greater than during a five minute run, which may cause further increases in the magnitude of relative breast kinematics. The initial work of Bowles and Steele (2003) only considered the superioinferior breast displacement, however, it is well established that the breast moves in three directions (Scurr et al., 2009) and the velocity and acceleration of the breast are important measures for understanding more about the biomechanics of the breast (Mason et al., 1999; McGhee et al., 2007; Scurr et al., 2010; McGhee, Steele, Zealey, & Takacs, 2012). Examining the magnitude of multiplanar breast kinematics over a common running distance, in each direction of movement, could increase knowledge of the breast during running, inform breast biomechanics protocols, provide vital information for sports bra design, and enable valid product assessments.

Another potential influence on the magnitude of breast kinematics during a prolonged run is the influence of increased sweat rates, and increased skin and core body temperature. During exercise, skin blood flow and sweat rates (Taylor & Groeller, 2008) are elevated from a thermoneutral state in response to increasing core body and skin temperature. The magnitude of the increase in core body and skin temperature and the associated thermoeffector responses, will depend upon the metabolic heat production, external environment, and clothing worn (Parsons, 2014). Bras are fitted closely to the thorax covering the breast tissue and often a large portion of the upper thorax. Furthermore, sports bras commonly include multiple layers of material with differing functions, with the material frequently covering more of the thorax and breast tissue than an everyday bra. Increased skin and core body temperature when wearing these garments may have implications for both the breast and bra during running. Firstly, the increased temperature of the skin and breast may alter the physical state of the adipose tissue within the breast, whereby the adipose tissue is close to reaching its melting point (transitioning from a semi-solid state to a liquid state) at approximately 32°C to 35°C (Schmidt-Nielson, 1946), which may result in a more malleable tissue. Secondly, the bras themselves may be influenced by temperature of the skin and breast, and amount of sweat absorbed. The properties of the fabrics incorporated in the bras, such as a bras elasticity, stretch-recovery rate, and strength may be affected, and therefore the ability of the bra to reduce the relative breast kinematics may be affected.

The aim of the current study was to quantify multiplanar breast kinematics during a five kilometre run in a low and high breast support. It was hypothesised that the magnitude of relative multiplanar breast kinematics would significantly increase throughout the five kilometre run in the low and high breast support conditions.

METHODS

Following institutional ethical approval, ten female volunteers (experienced treadmill and outdoor runners currently training ≥ 30 min, ≥ five times per week) with a mean and standard deviation (SD) age of 23 years (2 years), body mass 62.1 kg (5.4 kg), and height 1.60 m (0.05 m), participated in this study. All participants provided written informed consent to participate. Participants had not had children and not experienced any surgical procedures to the breast. Participants' bra size was measured employing the best fit criteria recommended by White and Scurr (2012), which ensures minimal movement of the bra over the skin, with the under-band, straps, and centre gore of the bras tightly fit to the thorax and breasts. Participants were required to fit either of the cross-graded bra sizes of 34D and 32DD.

Participants performed two five kilometre treadmill runs on separate days, 24 to 72 hours apart; once in a low breast support (everyday t-shirt bra) and once in a high breast support (Shock Absorber, B4490 sports bra) (Figure 1). Participants selected a comfortable running speed, which they felt they could maintain for the duration of the run, this ranged from 8.5 $km \cdot h^{-1}$ to 10.5 $km \cdot h^{-1}$, with an average of 9 $km \cdot h^{-1}$ (1 $km \cdot h^{-1}$). Once selected, this speed remained constant throughout all run trials. Participants wore the same footwear and lower body clothing for all trials.

----- INSERT FIGURE 1 HERE -----

Six retro-reflective hemi-spherical markers (diameter of 12 mm) were positioned with hypo-allergenic tape on the following anatomical landmarks; the suprasternal notch, the left and right anterior inferior aspect of the 10^{th} ribs, on the bra directly over the right nipple (Scurr et al., 2010; 2011) (Figure 2), and one positioned on the lateral aspect of the left heel to identify gait cycles (Scurr et al., 2009; 2010; 2011).

------ INSERT FIGURE 2 HERE -------

Three-dimensional coordinates of the six markers were tracked by eight calibrated Oqus infrared cameras (Qualisys, Sweden) sampling at 200 Hz. The eight cameras were positioned in an arc around the treadmill. Cameras recorded the final ten seconds of the first two minutes of the running. The average distance covered within this time was 322 m (64 m). Following this, cameras recorded for ten seconds within the final 100 m of each kilometre interval following this. With participants completing the five kilometre runs at different treadmill speeds the kilometre intervals were on average at 6.6 minutes (0.3 minutes), 13.1 minutes (0.7 minutes), 19.6 minutes (1.0 minutes), 26.2 minutes (1.4 minutes), and 32.7 minutes (1.7 minutes).

Markers were identified and three-dimensional data reconstructed in the Qualisys Track Manager software (Qualisys, Sweden). The global coordinate system identified x' as the line of progression on the treadmill (anteroposterior), y' as mediolateral, and z' as superioinferior (Figure 2). Raw three-dimensional coordinate data were exported from

Qualisys to a Fast Fourier Transform (FFT) program in MATLAB (MathWorks, UK). A cut-off frequency of 13 Hz was selected for the low pass filter with the majority of the signal power reported below this frequency. Filtered three-dimensional coordinates for the markers on the thorax, nipple, and heel were then exported to Visual3D (C-Motion, Inc.).

To establish relative breast kinematics, independent to the 6 *dof* movement of the thorax, an orthogonal segment coordinate segment converted global coordinates of the right nipple to relative coordinates using a transformation matrix within Visual3D. Three non-collinear markers positioned on the thorax were used to define the segment coordinate system, with the left and right anterior inferior ribs identified as the medial and lateral locations of the distal end of the segment and the suprasternal notch as the proximal end. A virtual mid-point was established between the medial and lateral points of the distal end (ribs) which extended to the suprasternal notch creating the superioinferior and primary axis (z''), the reference frontal plane (y′-z′) was then defined using the three markers, with vector y'' perpendicular to the z′ axis. Vector x'' was directed anterior to this plane, and using the right hand rule was perpendicular to z'' and y'' (Mills, Loveridge, Milligan, Risius, & Scurr, 2014).

Using the relative nipple coordinates, minima positional coordinates were subtracted from maxima coordinates of the right nipple, during each gait cycle (n = 5) (Scurr et al., 2009; 2010) to calculate breast range of motion in three-dimensions. First (velocity, $m \cdot s^{-1}$) and second (acceleration, $m \cdot s^{-2}$) derivatives of the relative nipple coordinates were calculated instantaneously for each sample (0.005 s), with peak values recorded during each gait cycle. Percentage increases were calculated for multiplanar breast kinematics from the first two minutes of running to each kilometre interval of the five kilometre runs for the low and high breast support conditions. To determine running gait cycles, instantaneous velocity of the heel was derived from the anteroposterior coordinates (Zeni, Richards, & Higginson, 2008).

All data were checked for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests, with normality assumed when $p > 0.05$. Homogeneity of variance was assessed using Mauchly's test of Sphericity, with homogenous data assumed when $p > 0.05$. Two-way repeated measures ANOVAs were performed to assess any significant differences ($p < .05$) in relative breast kinematics in each direction of movement, between and within low and high breast supports across the five kilometre run (six intervals). *Post hoc* pairwise comparisons with Bonferroni adjustment were performed following the two-way repeated measures ANOVAs.

RESULTS

Relative breast range of motion

The magnitude of relative multiplanar breast range of motion in the low breast support, during the five kilometre run is presented in figure 3. Percentage increases in multiplanar breast range of motion were reported from the first two minutes to the second kilometre interval (13.1 minutes of running). After this time point no further percentage increases were reported in either the anteroposterior or mediolateral range of motion. However, the superioinferior breast range of motion continued to increase, with significant increases ($p < .05$) reported between two minutes of running to the first, fourth, and fifth kilometres. The greatest percentage increase in multiplanar breast range of motion from the first two minutes was reported at the fifth kilometre (32.7 minutes of running) in the superioinferior direction (23%). However, the greatest change in multiplanar breast range of motion, between two consecutive distance intervals, was reported in the superioinferior breast range of motion between the first two minutes of running and first kilometre interval (14%).

----- INSERT FIGURE 3 HERE -----

The magnitude of relative multiplanar breast range of motion in the high breast support, during the five kilometre run is presented in figure 4. A similar pattern is reported when participants wore the high breast support, whereby percentage increases were reported in multiplanar breast range of motion from the first two minutes of running up until the second kilometre interval (13.1 minutes of running). However, percentage increases were reported to increase further in the mediolateral range of motion until the third kilometre (19.6 minutes of running), and until the fifth kilometre in the superioinferior breast range of motion.

----- INSERT FIGURE 4 HERE -----

Significant ($p < .05$) increases were reported from two minutes of running to first and fifth kilometre intervals in anteroposterior range of motion, to the fourth and fifth kilometre intervals in the mediolateral range of motion, and to the third, fourth, and fifth kilometre intervals in the superioinferior breast range of motion. The greatest relative percentage increase in multiplanar breast range of motion from the first two minutes was reported at the fifth kilometre interval (32.7 minutes of running) in the superioinferior direction, a 34% increase from the baseline. However, the greatest change in multiplanar breast range of motion, between two consecutive distance intervals, was reported in the superioinferior direction between the first two minutes and first kilometre interval (6.6 minutes of running) (20%).

Relative breast velocity

When participants wore the low breast support, percentage increases in peak relative multiplanar breast velocity were seen from the first two minutes of running until the second kilometre interval (13.1 minutes of running) (Figure 5), at this time point the greatest increase in anteroposterior breast velocity is reported (27%). Furthermore, the greatest percentage increase in anteroposterior breast velocity, between two consecutive distance intervals in the run, was seen between the first and second kilometre intervals, a difference of 22%. Whereas, the greatest relative increases in mediolateral and superioinferior breast velocity, between consecutive distance intervals, occurred between the first two minutes to first kilometre interval (6.6 minutes of running). Peak anteroposterior and mediolateral breast velocities did not increase past the second kilometre of running (13.1 minutes of running); however, significant increases ($p < .05$) were reported in peak superioinferior breast velocity at the fourth and fifth kilometre intervals.

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Percentage increases were reported in the peak multiplanar breast velocity over the first three consecutive distance intervals (322 m, first, and second kilometres) when participants wore the high breast support (Figure 6). Percentage increases in the mediolateral and superioinferior velocity continued to increase until the third kilometre of running; at this point the superioinferior velocity reached its greatest increase (37%) from the first two minutes of running.

----- INSERT FIGURE 6 HERE -----

The greatest percentage increases in peak anteroposterior and mediolateral velocity, between two consecutive distance intervals, were reported between the first two minutes (322 m) and first kilometre interval (6.6 minutes of running), however, this was reported between the first (6.6 minutes of running) and second (13.1 minutes of running) kilometre intervals for the superioinferior breast velocity (Figure 6).

Relative breast acceleration

In the low breast support, percentage increases in peak multiplanar breast acceleration were reported from the first two minutes of running until the second kilometre interval (13.1 minutes of running) (Figure 7). However, percentage increases were reported in the superioinferior and mediolateral breast acceleration past this time point. Percentage increases in peak superioinferior acceleration continue to rise until the fifth kilometre interval (32.7 minutes of running), reaching a peak increase of 27%. At this time a significant increase ($p < .05$) was reported in peak superioinferior breast acceleration from the first two minutes of running to the fifth kilometre interval.

----- INSERT FIGURE 7 HERE -----

The greatest percentage increases in peak multiplanar breast acceleration, between two consecutive distance intervals, were reported within the first two kilometres of running (13.1 minutes of running), with increases in mediolateral and superioinferior acceleration occurring between two minutes and the first kilometre, and between the first and second kilometre intervals for the anteroposterior breast acceleration.

Percentage increases in peak multiplanar breast acceleration were seen to increase gradually from the first two minutes to the second kilometre interval (13.1 minutes of running) in the high breast support condition (Figure 8). The greatest percentage increases in peak multiplanar breast acceleration, between two consecutive distance intervals, were reported between the first and second kilometres. The anteroposterior and mediolateral breast acceleration reached peak magnitudes at the second kilometre interval. Whereas, the superioinferior breast acceleration continued to increase at each time interval and reached a peak at 32.7 minutes of running (5^{th} km). A significant ($p < .05$) increase in peak superioinferior breast acceleration was reported from the first two minutes of running to the fifth kilometre interval.

----- INSERT FIGURE 8 HERE -----

DISCUSSION

Understanding whether run distance influences the magnitude of multiplanar breast kinematics may increase our understanding of the breast and bra during running, help to provide recommendations for breast biomechanics protocols, and may provide insight into product performance during common running distances. This study aimed to quantify the magnitude of multiplanar breast kinematics during a five kilometre treadmill run in a low and high breast support condition, to determine if breast kinematics differed over a prolonged treadmill run. The key findings were that significant increases in multiplanar breast kinematics occurred during a five kilometre run in a low and high breast support, with the greatest increases between two consecutive distance intervals commonly occurring between the first two minutes (322 m) to the first kilometre interval. The greatest relative percentage increases in multiplanar breast range of motion (34%), velocity (37%), and acceleration (41%) over the five kilometre run, occurred in the superioinferior direction when participants wore the high breast support.

The current study identified previously unreported increases in multiplanar breast kinematics over a five kilometre run in a low and high breast support, which has implications for past and future breast biomechanics protocols. Excluding breast velocity in the low breast support, the greatest overall increases in multiplanar breast kinematics in the low and high breast supports, were reported in the superioinferior direction. These findings indicate that superioinferior breast kinematics were subject to the greatest change in magnitude over a five kilometre run, with up to 41% increase in breast acceleration. It is important to consider what impact this may have on the breast tissue during running and whether these increases in magnitude could pose an injury risk to the breast tissue. Greater relative accelerations of the breast tissue will lead to greater resultant breast forces, which could lead to tissue strain. However, it is assumed that the potential for strain on the breast tissues is considerably less in the high breast support condition as a result of the structured design and superior support of this bra, when compared to the low breast support.

When examining the greatest increases in multiplanar breast kinematics between two consecutive distance intervals of the run in the low and high breast supports, the greatest increases were frequently reported between the first two minutes and the first kilometre interval (6.6 minutes of running). Excluding the superioinferior breast kinematics, which continued to increase, it is suggested that the magnitude of anteroposterior and mediolateral breast kinematics begin to plateau around the second kilometre interval (13 minutes of running). Based upon the steep increases in breast kinematics within the first kilometre of running, it is recommended that breast biomechanics protocols should examine breast kinematics over at least one kilometre (approximately seven minutes of running at an average speed of 9 km.hr^{-1}), and where possible up to 13 minutes of running to obtain a more representative measure of breast kinematics for exercising females.

Another potential explanation for the increases in breast kinematics is the influence of increased skin and body temperature on the breast tissue. The participants completed the five kilometre run in a biomechanics laboratory, at an ambient temperature of 19°C. Though the high breast support incorporates wicking fabrics, designed to draw moisture away from the body, the increased material thickness and skin coverage may have heightened the thermal insulation of this bra, which may have increased the local skin and breast temperature more than the low breast support. It is proposed that a gradual increase in the temperature of the breast tissue could have led to the adipose tissue in the breast reaching its melting point and transitioning from a semi-solid state to a liquid state (Schmidt-Nielson, 1946), resulting in a more malleable tissue. This potential change in the adipose tissue within the breast could explain the significant increases in breast kinematics throughout the five kilometre run.

The potential decline in the support performance of the two breast support garments may provide further explanation for the reported increases in multiplanar breast kinematics throughout the five kilometre run. Increased skin temperatures and any sweat absorbed by the bra during the five kilometre run may have influenced the mechanical properties of the fabrics (Ayres, White, Hedger, & Scurr, 2013) such as elasticity, recovery and strength. Ayres et al., (2013) reported significant increases in the mass of two sports bras following 20 minutes of exercise, likely due to the accumulation of unevaporated sweat. Within the current study, the high breast support contained polyester, polyamide and elastane, whereas the low breast support incorporated only polyamide and elastane Lycra. The blending of intelligent fibres ensures the sports bra contains diverse mechanical properties, with polyester known for its strength and elastic-recovery properties, making it the single most commonly used fibre for sportswear (Shishoo, 2008). It is proposed that the low breast support may be subjected to greater stretch rate over time without polyester fibres incorporated into this bra. However, the high breast support (sports bra) may have gained more mass than the low support due to its greater material thickness, coverage, and wicking properties. A further consideration of the interaction between the breast and bra is that of relative movement between the breast and bra. Breast movement was monitored by a marker positioned directly over the nipple on top of the bra, and therefore any movement of the breast inside the cup of the bra is unknown and could influence the resulting breast kinematics. The potential for this was reduced by the professional bra fit and the style of the sports bra. An important factor of the White and Scurr (2012) bra fitting method is to ensure the cup of the bra is not baggy or gaping and the breast tissue fills the cup of the bra. The style of bra was a soft cup sports bra, and therefore deformed, to an extent, as the breast displaced during the gait cycle. The need to quantify the potential movement of the breast inside a bra is evident and should be a focus of future work within this area of research.

Running kinematics were not measured during the current study, however it is important to consider whether running kinematics could have changed between support conditions and over time (Hardin, Van Den Bogert, & Hamill, 2004; Williams & Cavanagh, 1987; Williams, Snow, & Agruss, 1991), and how this may have influenced the reported differences over the five kilometre run. With breast kinematics measured relative to the thorax segment, it could be assumed that any changes in this segments kinematics could impact upon the resulting breast kinematics (White, Scurr, & Smith, 2009). The influence of breast support on running kinematics has received little attention and should be a focus of future work. Understanding the potential improvements or detriments to running kinematics based upon the breast support worn, would help to inform exercising females of the most appropriate support for optimal sporting performance.

The findings of this study have important implications for breast biomechanics assessment protocols, the evaluation and marketing of breast support performance, and females exercising for prolonged durations. Based upon the results of this study both breast biomechanics protocols and product assessment protocols should carefully consider the duration of run employed. The results of the current study demonstrate increases in multiplanar breast kinematics until the second kilometre interval (13 minutes), and increases in superioinferior breast kinematics until the fifth kilometre interval (32.7 minutes of running). It is important to consider the implications these findings have on females exercising for this duration (five kilometre run) or longer and those with larger breast masses. Dependent upon the support worn, it could be hypothesised that superioinferior breast kinematics may continue to increase over a longer run (e.g. half marathon or marathon), putting these exercising females under a greater risk of tissue strain at the breast. Brown, White, Brasher, and Scurr (2013) identified that 91% of female London marathon runners reported to wear a sports bra, but identified only 21% of this population rated their knowledge of breast health and bras as above average. It is crucial that exercising females have a good understanding of appropriate breast support and the performance of sports bra over time. Within the current study increases in multiplanar breast kinematics were reported in both the low and high breast support conditions over a five kilometre run, however, the magnitude was significantly reduced in the high breast support (sports bra) when compared to the low support (everyday bra), providing superior support to the breasts.

CONCLUSION

This study found significant increases in multiplanar breast kinematics during a five kilometre treadmill run in a low and high breast support, with the steepest increases occurring between the first two minutes of running to the first kilometre interval (on average 6.6 minutes of running at 9 $km.hr^{-1}$). Based upon these findings it is recommended that breast biomechanics protocols incorporate at least seven minutes of running to obtain a more representative measure of breast kinematics for exercising females. The superioinferior breast kinematics displayed the greatest percentage increase from the start to the end of the five kilometre run, and it is possible that the magnitude may continue to increase during prolonged running before reaching a plateau. It was suggested that these findings were due to the combined effect of a small degree of tissue strain due to the repeated loading on the breast during prolonged treadmill running, an increased temperature of the breast tissue, and finally the deterioration in the performance of the fabric properties of the breast supports during the run. Due to the superior support offered by the high breast support, these bras are still recommended over a lower breast support to reduce relative breast kinematics.

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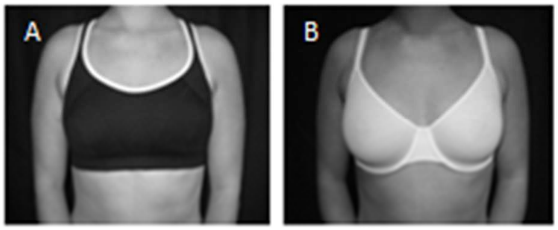

Figure 1 (A) High support condition sports bra: B4490, Shock Absorber level 4 support, made from 57% polyester, 34% polyamide, and 9% elastane. (B) Low support conditions everyday bra: Marks and Spencer Seamfree Plain Under wired T-Shirt Bra, non-padded, made from 88% polyamide and 12% elastane lycra.

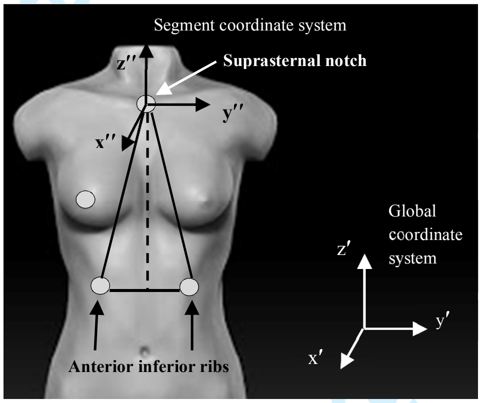

Figure 2 Marker locations, axes and coordinate systems for the global coordinate system (x', y', z') and segment coordinate system (x", y", z").

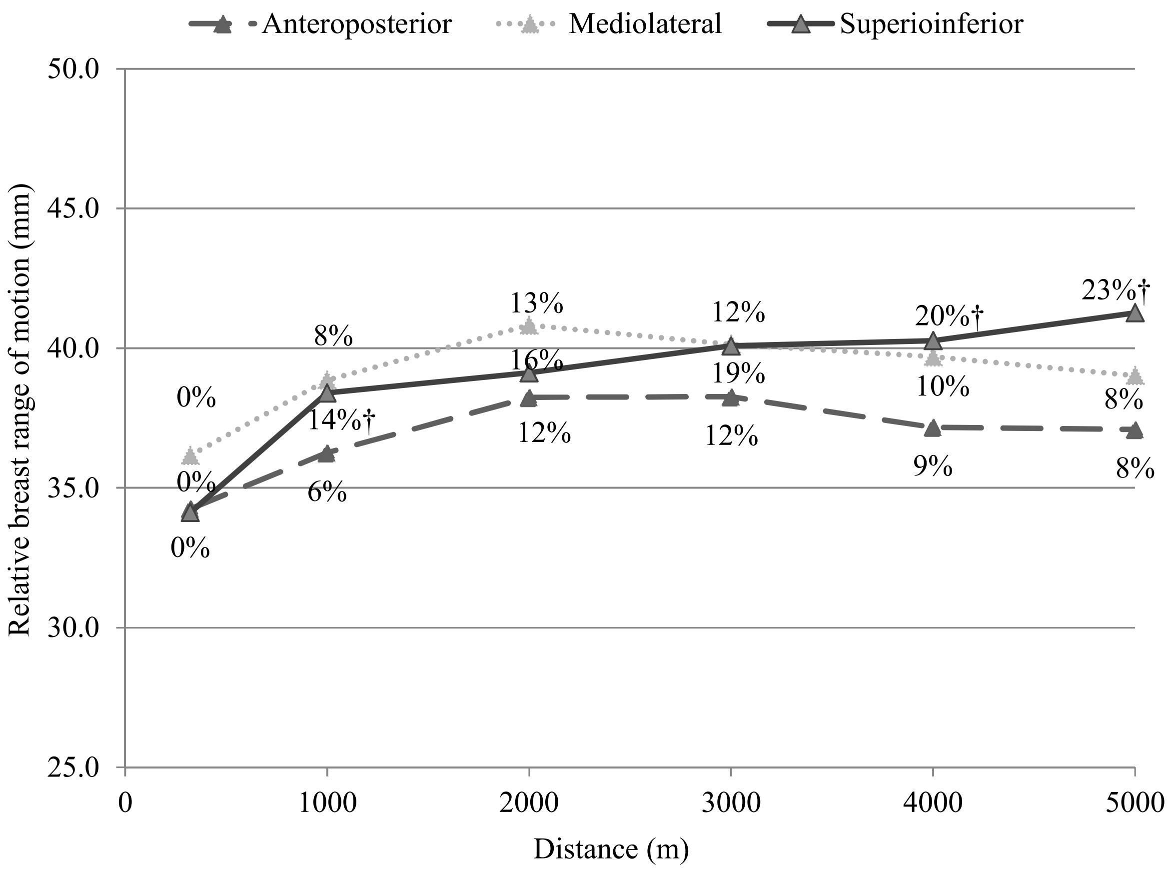

Figure 3. Mean multiplanar breast range of motion (mm) during the five kilometre run, and percentage increases from the first two minutes of running (average distance reached 322 m ± 64 m) to each consecutive distance interval in a low breast support.

N.B. † Significant increase in breast range of motion from the first two minutes to the kilometre interval, $p < 0.05$

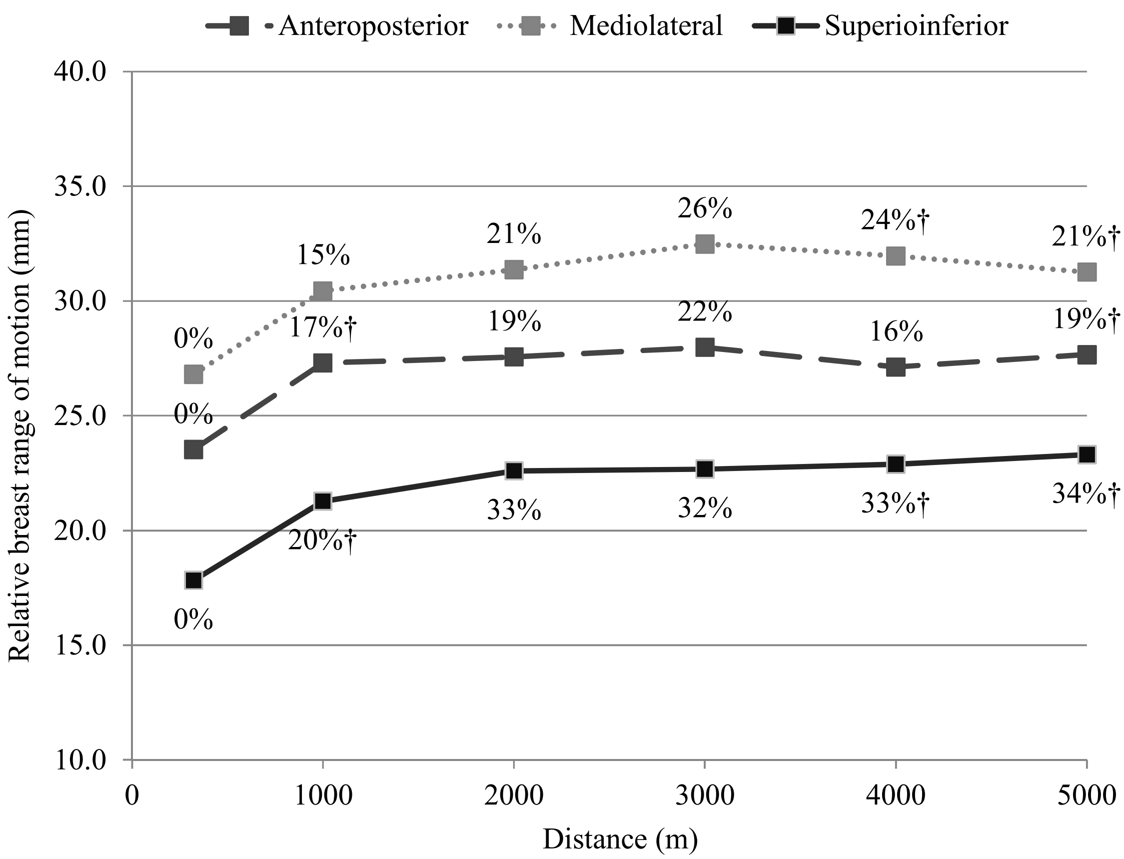

Figure 4. Mean multiplanar breast range of motion (mm) during the five kilometre run, and percentage increases from the first two minutes of running (average distance reached 322 m ± 64 m) to each consecutive distance interval in a high breast support.

N.B. † Significant increase in breast range of motion from the first two minutes to the kilometre interval, $p < 0.05$

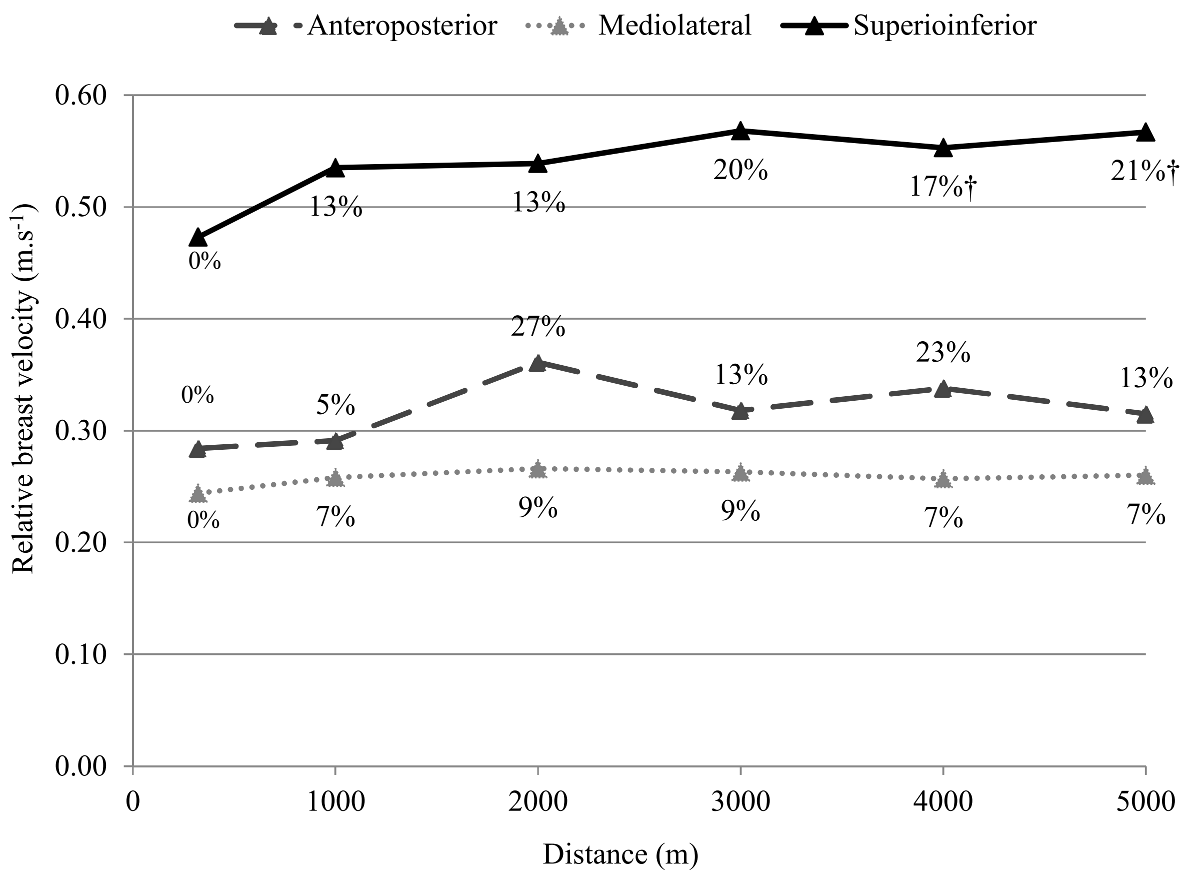

Figure 5. Mean peak multiplanar breast velocity ($m.s^{-1}$) during the five kilometre run, and percentage increases from the first two minutes of running (average distance reached 322 m ± 64 m) to each consecutive distance interval in a low breast support.

N.B. † Significant increase in peak breast velocity from the first two minutes to the kilometre interval, $p < 0.05$

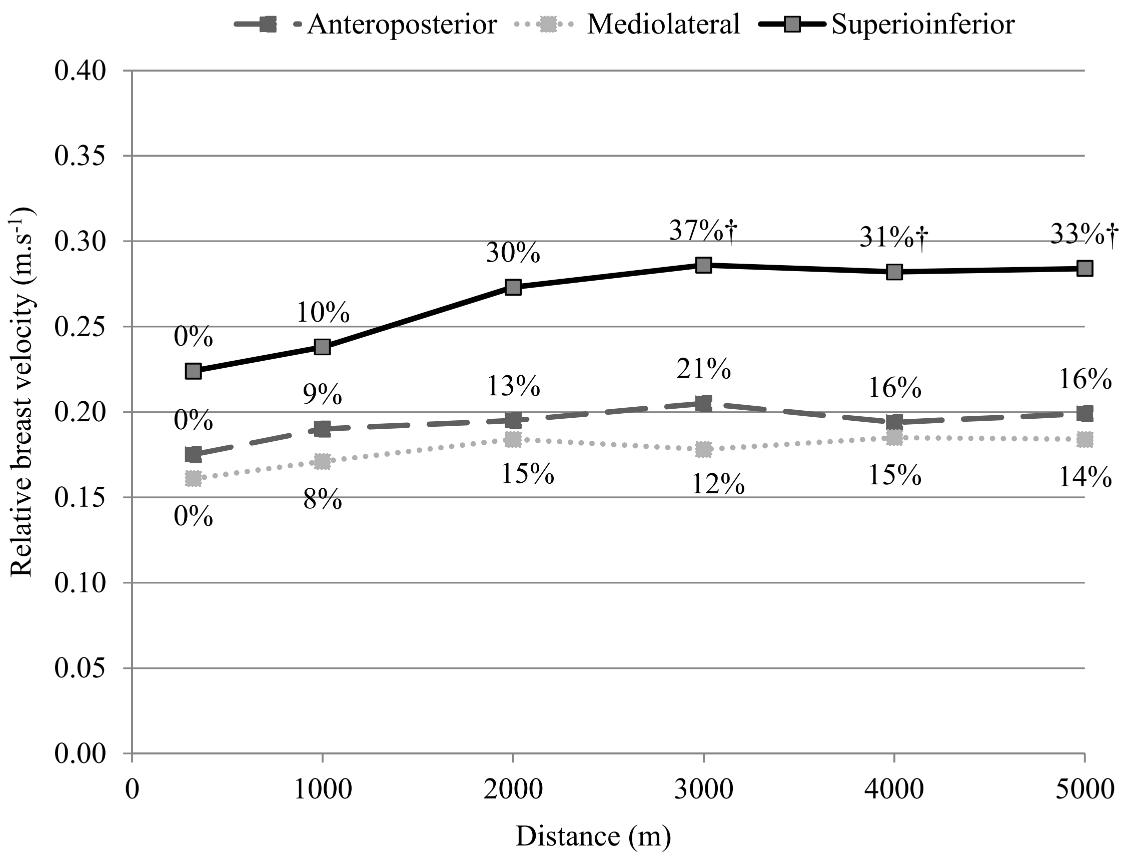

Figure 6. Mean peak multiplanar breast velocity (m.s^{-1}) during the five kilometre run, and percentage increases from the first two minutes of running (average distance reached 322 m ± 64 m) to each consecutive distance interval in a high breast support.

N.B. † Significant increase in peak breast velocity from the first two minutes to the kilometre interval, $p < 0.05$

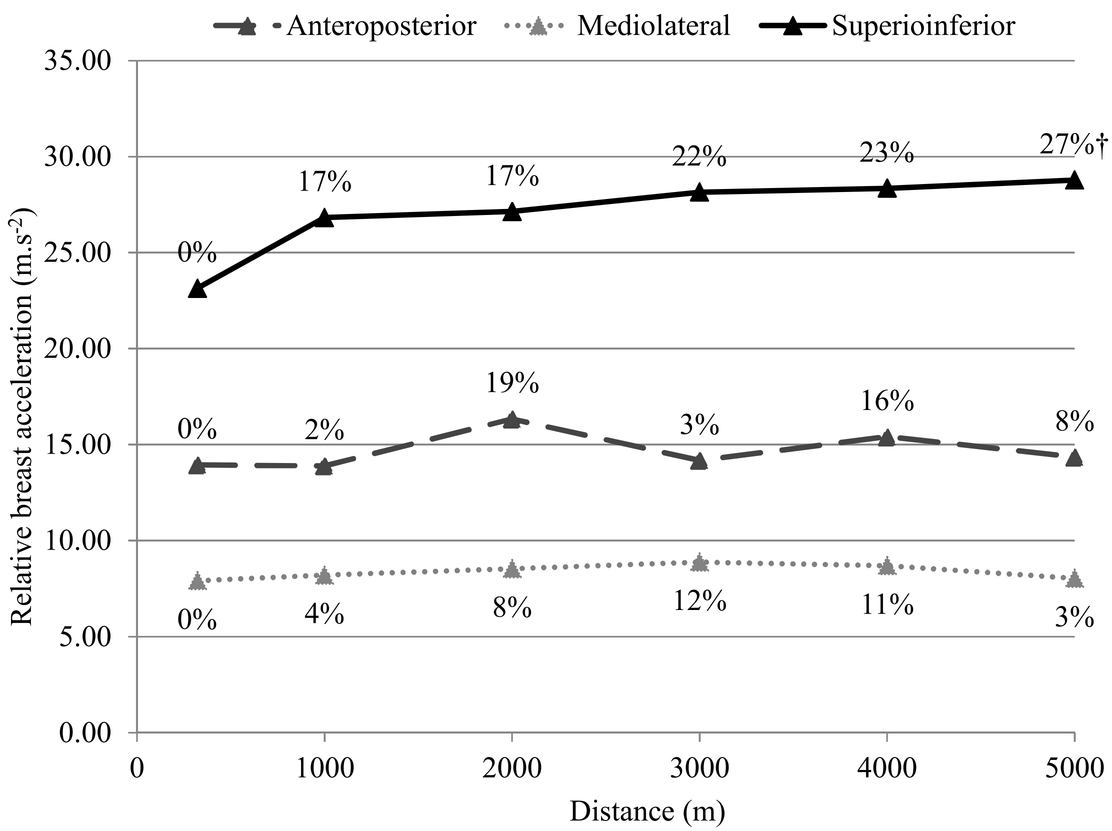

Figure 7. Mean peak multiplanar breast acceleration ($m.s^{-2}$) during the five kilometre run, and percentage increases from the first two minutes of running (average distance reached 322 m ± 64 m) to each consecutive distance interval in a low breast support.

N.B. † Significant increase in peak breast acceleration from the first two minutes to the kilometre interval, $p < 0.05$

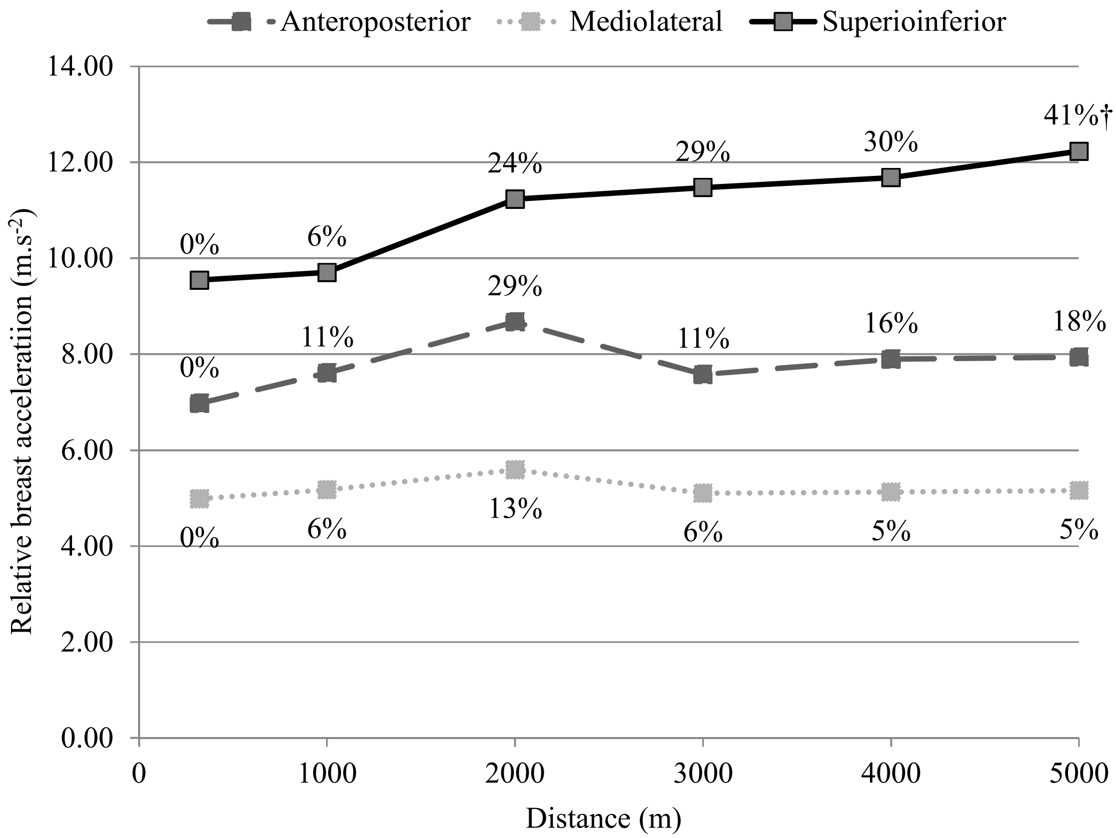

Figure 8. Mean peak multiplanar breast acceleration ($m.s^{-2}$) during the five kilometre run, and percentage increases from the first two minutes of running (average distance reached 322 m ± 64 m) to each consecutive distance interval in a high breast support.

N.B. † Significant increase in peak breast acceleration from the first two minutes to the kilometre interval, $p < 0.05$