



## **Reductions in Kinematics from Brassieres with Varying Breast Support**

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### ABSTRACT

*International Journal of Exercise Science* 12(1): 402-411, 2019. Given the abundance of brassieres, manufacturers, and investigations of bras, it remains unclear whether the continued development of bras will provide many additional improvements in support. This study measured performance of sport bras including 4 popular bras and a new style bra at reducing breast motion during five common exercises. Bras demonstrated varying effectiveness and consistency across exercises at reducing undesirable breast motion, (hereafter referred to as kinematics). The new style bra significantly reduced vertical breast displacement and acceleration more consistently than other bras. When significant differences between bras were detected, the newer bra provided 31% greater reduction in vertical displacements and accelerations on average than other bras. Lateral reductions were smaller, less significant and no differences between bras were detected. When participants evaluated bras in terms of performance and ease of use, the newer bra was rated better than other bras by nearly a two to one ratio. There were no differences in how the bras felt, or in terms of pain and discomfort. Correlations between participant comfort and reductions in kinematics were weak and inconsistent. Results suggest continued bra development is possible in order to reduce undesirable motion especially in terms of reducing lateral motion. Additional investigation is required to examine the mechanistic reasons why bras improve comfort and potentially performance.

**KEY WORDS:** Motion, female, displacement, acceleration

### INTRODUCTION

By nature, gravity is a downward force and causes vertical motion on objects that are unable to resist the force (11). In addition, inertial forces caused by changes in velocity result in motion and force components oriented not only in vertical but also horizontal directions. Human breasts are comprised of elastic fibers in the form of suspensory ligaments in addition to smooth muscle and lie in close proximity to skeletal muscles (10). As a result, the elastic tissue cannot be actively controlled in resisting the gravitational or inertial forces encountered during daily activities or exercise, which presents a particular challenge for females.

Considerable evidence within the medical, scientific and lay communities has led to the conclusion that female breasts should be supported by brassieres (bras). Bras support the breasts and help avoid deleterious effects of external forces which tend to accumulate over time and cause fatigue related problems to breast tissue (13). The first bra product was developed slightly more than one hundred years ago and immediately became an essential part of women's apparel (3). Since then, clothing designers have continued to experiment with shapes, patterns, and features of bras in order to optimally support the breasts. At present, there are mixed reviews concerning variations in supporting properties of different bras and it remains unclear whether perceptions of bra performance and comfort align with measured alterations in kinematics provided by the bras.

One of the earliest documented studies to investigate breast motion in natural unsupported as well as bra supported conditions replicating activities encountered in daily life and during exercise did so using video photography of reference marks on human skin or the bras (5). In the past decade, investigations have advanced to use of standard motion capture techniques. As is common in gait analysis studies, retroreflective markers are attached to anatomical landmarks on the limb segments (or breasts), and reactions between the feet and ground are recorded from load plates. Recent studies have: compared breast kinematics for overground and treadmill running (16), studied effects of breast support on upper extremity segmental kinematics while distance running (8) and explored relationships between anthropometric descriptors and breast kinematics (18). Even more studies have focused on the following aspects related to bra performance: discomfort associated with breast vertical velocity while running in water compared to over ground (6), ground reaction forces both without (2, 17) and with breast support (17), and breast-bra forces as related to breast size (7). However, only a few studies (5, 12, 16, 17) have compared the effectiveness of different bras at supporting the breasts and reducing undesirable kinematics resulting from vigorous exercise or activity. In general, previous work has demonstrated that certain types of bras reduce breast motion. The question remains whether the breast support clothing industry can continue to develop more effective support solutions.

The first purpose of this study was to measure and compare breast kinematics when participants wore different bras of renown, as well as a start-up manufacturer. It was hypothesized that bras would demonstrate varying effectiveness at reducing undesirable displacements and accelerations of the breasts while participants engaged in exercises replicating motions representative of those encountered during daily life, fitness activities and sport. A second purpose was to investigate the relationship between perceptions concerning comfort and performance and alterations in kinematics encountered during the exercises. For this secondary purpose, it was hypothesized higher levels of perceived comfort and performance would be reported when the bras reduced breast displacements and accelerations.

## **METHODS**

### *Participants*

Thirty female participants were recruited for this study. After explanation of the study and familiarization with the instrumentation, participants were informed of associated risks and provided written informed consent to participate in testing in accordance with requirements of the Institutional Review Board at Central Michigan University. Participants were recruited from among women active in sports and exercise programs in the local and university communities. Consequently, participants' breasts were of a wide array of sizes from a traditional AA through traditional DD+ (mean cup size: 13.2 cm., S.D. 3.3 cm., range: 8.6-21.6 cm.).

### *Protocol*

After pre-measurement for breast size, each participant received 5 different sport bras: Shefit (Ultimate Sports), Adidas (Techfit), Nike (Pro Alpha), Underarmour (Eclipse), and Brooks Moving Comfort (Uprise Crossback for traditional size A, Fiona for traditional size B-DD, Jubralee for traditional E-F). All bras were fitted to participants by a trained bra fitter in order to ensure properly sized bras were worn. For bras other than Shefit, standard sizing information and charts were followed according to manufacturer provided data.

An experimental paradigm was developed to allow for the recording of motion capture data for measurement of breast kinematics. Each participant performed five sports related exercises, in six different conditions while wearing each of the five bras (Shefit-S, Adidas-A, Nike-N, Underarmour-U, Moving Comfort-M); and wearing no bra (Control). The exercises included: running in place with high knees for 7 seconds; jumping jacks (jacks) for 7 seconds, running from a standing start to distance of 12 meters, 5 side twists, and walking a distance of 12 meters. For each participant, the five exercises were performed in the same order, and the order of bras (and Control condition) was randomized. Instructions to each participant were to perform each exercise in a relatively quick but comfortable and controlled motion. As such, participants practiced each exercise until comfortable with the motion. Participants performed 3 trials of each exercise.

Following familiarization of the testing protocol and nature of the five exercises, participants were instrumented with retro-reflective markers. 47 markers (14.0 mm diameter, B&L Engineering, Santa Ana, CA, USA) were applied. 39 markers were placed on anatomical landmarks according to the Vicon Plug-in-Gait Full Body Model and 4 additional markers were applied to each breast, or on the bra over the breast (Figure 1). Marker motions were recorded with a 12-camera Vicon T160 Motion Capture system at 100 Hz.

After testing, each bra was rated on a 0-10 numerical visual analog scale (VAS) (15) for pain adapted for the present study where: 0 represents comfortable (no pain), 5 represents uncomfortable, and 10 corresponds to painful. At the end of testing for all bras two open-ended questions were asked: "Which bra felt and performed the best?" and, "Which bra was easier to put on and take off?"

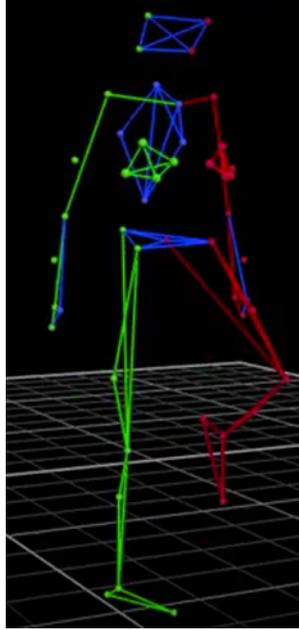


Figure 1: Participant performing exercise with 47 markers attached. 39 markers were applied to anatomical landmarks in accordance with the standard Vicon plug-in-gait model and 4 markers were applied to each breast or bra (for bra conditions).

Following reconstruction and labeling of data within Vicon, marker coordinate trace files were processed through custom written scripts (Matlab, Mathworks, Natick, MA) to calculate kinematics describing the motion of each participant. Markers attached to tenth thoracic and seventh cervical vertebra, as well as left and right shoulders, were used to virtually construct a coordinate system on the thorax. The three-dimensional displacement of the right breast nipple marker relative to the always-moving thorax was calculated. In order to evaluate if conditions were performed in a similar manner, performance velocity was calculated as thorax vertical velocity for high knees and jacks, as thorax horizontal velocity for the side twists and as thorax forward velocity for walking and running. A 10 Hz Butterworth filter was applied to the breast displacement data. Breast acceleration was determined with two successive calculations of numerical forward-differentiation. Then, a 10 Hz Butterworth filter was applied to breast acceleration (18). The three-dimensional displacements and accelerations were then referred to the thorax-based coordinate system in order to calculate displacement and acceleration in meaningful anatomical directions: superior-inferior (up-down) and medial-lateral (side-side). The initial and final time portions of each trial were cropped (i.e. excluded) from calculations in order to eliminate start effects and slowing as trials were nearly completed. Maximum displacements and accelerations of the right breast were extracted from the trials in order to make comparison between bras for each exercise condition.

#### *Statistical Analysis*

A power analysis conducted with G\*POWER 3.1 (Universitat Kiel, Germany) determined that 30 participants were sufficient to achieve a power of 0.90 for detecting an effect size of 0.8 with probability of type I error,  $\alpha = 0.05$ . Summary statistics were calculated for the maximum displacements and accelerations and the data analyzed with ANOVA to determine if differences

in mean maximum displacements and accelerations were significant between bras. Following initial ANOVA for each outcome, secondary ANOVAs were performed to assess if differences existed between bras within a given exercise. When ANOVA revealed significant differences, pair-wise post-hoc comparisons were performed between individual bras with Tukey-Kramer Honest Significant Difference criterion ( $\alpha=0.05$ ) (Matlab, Mathworks, Natick, MA). Perception of breast comfort data are ordinal numbers and therefore differences in median comfort between bras were assessed with Kruskal-Wallis test. Relationships between kinematic outcomes (i.e. maximum breast displacements, accelerations in medial-lateral, inferior-superior directions) and breast comfort were assessed by calculating Spearman’s correlation coefficients.

**RESULTS**

**Performance velocity.** Across all trials and exercises, there were no differences in performance velocity with bras compared to Control during all exercises, except for running (Table 1). While running, compared to Control, the exercise was performed 7% faster while wearing all bras, but there were no differences between bras. However, when evaluating the rest of exercises individually it was found that high knees was performed 9% faster with N as compared to Control ( $p=0.01$ ). Jacks was performed 4% faster while wearing A while no other differences were statistically significant. There were no differences between bras for any exercise.

**Table 1.** Mean performance velocity (standard error) (meters/second).

Condition	H	J	R	S	W
C	0.61 (0.03)	0.76 (0.02)	3.26 (0.11)	0.19 (0.01)	1.56 (0.03)
A	0.64 (0.02)	*0.79 (0.01)	*3.47 (0.09)	0.21 (0.01)	1.53 (0.03)
M	0.64 (0.02)	0.77 (0.01)	*3.42 (0.09)	0.20 (0.01)	1.58 (0.04)
N	*0.66 (0.02)	0.78 (0.01)	*3.46 (0.08)	0.19 (0.01)	1.60 (0.04)
U	0.65 (0.02)	0.78 (0.01)	*3.48 (0.09)	0.21 (0.01)	1.53 (0.03)
S	0.64 (0.03)	0.77 (0.01)	*3.45 (0.01)	0.20 (0.01)	1.58 (0.04)

Exercise conditions in columns: High Knees-H, Jumping Jacks-J, Running-R, Side Twists-S, Walking-W.

Bra conditions in rows: Control-C, Adidas-A, Moving Comfort-M, Nike-N, Under Armour-U, Shefit-S.

\* Significant difference ( $p<0.05$ ) between Condition and Control. Pairwise differences described in results.

Performance velocity was calculated as thorax vertical velocity for high knees and jacks, as thorax horizontal velocity for the side twists and as thorax forward velocity for walking and running.

**Breast displacement.** Across all exercises, all bras reduced maximum vertical (superior-inferior) breast displacement in a statistically significant manner ( $p<0.0001$ ) (Table 2). Significant differences between bras depended on exercise. S reduced vertical motion more than A, N, and U, when performing high knees, running, and walking. When performing jacks, S provided greater reduction compared with A, M, N, and U. Lastly, for the side twists, A, N and S significantly reduced vertical displacements compared to Control condition, but there were no differences between bras. When significant differences between the bras were found, S provided 31% greater reduction in vertical displacement on average than other bras.

Analysis of the lateral (medial-lateral) breast motion determined that all bras reduced breast displacement in a statistically significant manner when compared to Control (Table 2). On an

exercise specific basis, none of the bras reduced side-side motion in a significant manner for high knees. For jacks, only M reduced side-side motion significantly. With running, S and M reduced lateral motion significantly compared to controls, but there were no significant differences between any bras. For side twists, no bras reduced lateral motion in a significant manner. Likewise, for walking, there were no significant differences in the side-side motion of the breasts between any bras and Control condition.

**Table 2.** Mean maximum displacement (standard error) (millimeters).

Condition		H	J	R	S	W
Superior-	C	59.3 (4.9)	70.3 (5.3)	43.7 (4.1)	14.3 (1.8)	12.0 (1.1)
Inferior	A	*39.7 (7.1)	*44.5 (4.0)	*24.6 (3.0)	*9.1 (0.9)	*9.8 (1.1)
	M	*32.4 (6.3)	*36.5 (2.5)	*20.7 (1.8)	12.3 (2.2)	*7.8 (0.8)
	N	*32.2 (2.6)	*46.4 (3.9)	*28.0 (2.7)	*9.9 (0.8)	*10.0 (1.1)
	U	*35.5 (3.5)	*48.8 (4.3)	*33.8 (4.0)	10.2 (0.7)	*10.3 (1.2)
	S	*18.9 (2.6)	*27.3 (1.8)	*13.9 (1.0)	*8.4 (0.6)	*5.7 (0.4)
Bra pair differences		‡†#	‡†#+%&@	‡†#@		‡†#@
Medial-	C	36.9 (3.3)	30.7 (3.4)	35.1 (2.9)	35.0 (4.3)	17.1 (1.2)
Lateral	A	29.5 (6.6)	15.9 (0.9)	23.2 (2.1)	32.3 (3.1)	10.8 (0.9)
	M	31.2 (8.0)	*16.5 (1.1)	*20.1 (2.1)	30.4 (3.1)	9.6 (0.9)
	N	25.1 (2.2)	19.1 (1.7)	28.9 (5.6)	31.7 (2.8)	11.1 (0.8)
	U	21.5 (1.4)	26.2 (7.3)	24.4 (2.5)	31.0 (2.4)	10.4 (0.8)
	S	22.7 (4.4)	19.2 (2.8)	*21.5 (3.4)	30.1 (2.4)	15.0 (6.3)
Bra pair differences		None				

Exercise conditions in columns: High Knees-H, Jumping Jacks-J, Running-R, Side Twists-S, Walking-W.

Bra conditions in rows: Control-C, Adidas-A, Moving Comfort-M, Nike-N, Under Armour-U, Shefit-S.

\* Significant difference (p<0.05) between Condition and Control. Pairwise differences described in results. Significant (p<0.05) pairwise bra differences: ‡ Shefit-Adidas, † Shefit-Nike, # Shefit-Under Armour, + Shefit-Moving Comfort, % Moving Comfort-Adidas, & Moving Comfort-Nike, @ Moving Comfort-Under Armour.

**Breast acceleration.** When evaluating the ability of bras to reduce vertical (superior-inferior) acceleration of the breast, all bras reduced maximum vertical acceleration compared to Control across all exercises, except for jacks and side twists (Table 3). S resulted in significantly greater reduction in vertical acceleration compared other bras for high knees. For jacks and walking, S provided greater reduction compared to A, N and U, with no difference between S and M (for jacks only). A, M, N and S all reduced vertical acceleration when compared to Control during running with individual differences found between S and N, S and U and between M and U (all p<0.05). Finally, with side twists, there were no significant differences between any bras in vertical acceleration. Again, when significant differences between the bras were found, S reduced vertical acceleration by 31% more on average than other bras.

When analyzing the effects of bras on the lateral (medial-lateral) acceleration of the breast it was determined that all bras reduced the outcome in a significant manner when compared to Control during high knees and jacks, with no differences between bras. No differences between bras and Control were found for running, side twists and walking (Table 3).

**Table 3.** Mean maximum acceleration (standard error) (centimeters/second<sup>2</sup>).

Condition		H	J	R	S	W
Superior-	C	32.2 (2.8)	33.0 (4.8)	28.0 (2.5)	5.1 (0.9)	6.4 (0.7)
Inferior	A	*18.5 (2.2)	*17.6 (1.7)	*15.2 (1.9)	2.7 (0.4)	*4.1 (0.6)
	M	*14.7 (1.3)	*12.6 (1.0)	*12.4 (1.2)	6.0 (3.3)	*3.3 (0.5)
	N	*17.6 (1.6)	*19.6 (2.6)	*15.5 (1.5)	2.7 (0.4)	*4.1 (0.6)
	U	*19.1 (2.1)	*18.6 (1.9)	21.4 (4.3)	2.9 (0.4)	*4.1 (0.5)
	S	*8.6 (0.7)	*9.4 (0.6)	*7.5 (0.7)	1.9 (0.3)	*2.1 (0.2)
Bra pair differences		‡†#+	††#	‡#@		‡†#
Medial-	C	23.4 (2.0)	16.9 (7.3)	15.3 (10.6)	7.5 (3.5)	6.4 (5.1)
Lateral	A	*13.5 (2.0)	*6.3 (2.4)	10.8 (1.2)	4.7 (1.4)	3.5 (0.4)
	M	*13.5 (1.2)	*5.7 (0.4)	8.9 (1.2)	5.9 (0.8)	3.2 (0.3)
	N	*13.3 (2.6)	*9.1 (0.3)	11.9 (1.0)	4.7 (2.0)	3.7 (0.3)
	U	*12.5 (0.8)	11.4 (3.5)	13.3 (2.6)	5.2 (1.0)	3.3 (0.3)
	S	*10.1 (0.8)	*7.3 (1.2)	10.6 (1.6)	3.5 (0.5)	5.1 (2.5)
Bra pair differences		None				

Exercise conditions in columns: High Knees-H, Jumping Jacks-J, Running-R, Side Twists-S, Walking-W.  
 Bra conditions in rows: Control-C, Adidas-A, Moving Comfort-M, Nike-N, Under Armour-U, Shefit-S.  
 \* Significant difference (p<0.05) between Condition and Control. Pairwise differences described in results.  
 Significant pairwise bra differences: ‡ Shefit-Adidas, † Shefit-Nike, # Shefit-Under Armour, + Shefit-Moving Comfort, @ Moving Comfort-Under Armour.

No differences between bras were found when each bra was rated for comfortability (p=0.82) (Table 4). The S bra was preferred by a nearly two to one ratio. (Table 4). Likewise, for the question regarding ease of putting on and taking off the bras, S bra was rated as easiest by nearly a two to one ratio.

**Table 4.** Perception of bra comfort (mean and standard error), performance and ease of use.

Condition	Comfort	Performance	Ease of use
A	4.0 (0.6)	4	6
M	3.2 (0.6)	6	7
N	3.4 (0.6)	3	2
U	3.5 (0.6)	6	4
S	3.2 (0.6)	11	11

Ratings of bra comfort are on a 0-10 numerical visual-analog scale. 0 is comfortable (no pain), 5 is uncomfortable, and 10 is painful. There were no differences in comfortability ratings of the bras (p=0.82). Performance and Ease are counts of the number of participants (out of 30) rating each bra as being best performing and easiest to don/doff, respectively. Bra conditions in rows: Adidas-A, Moving Comfort-M, Nike-N, Under Armour-U, Shefit-S.

Correlations between maximum breast displacements and accelerations in the medial-lateral and inferior-superior directions and perceived breast comfort were generally quite weak, ranging up to a maximum R<sup>2</sup> = 0.22, and lacked differences or trends between kinematic outcomes, or outcome directions. For each of the directions for which correlations were calculated, only 3 out of 10 outcomes (5 bras x displacements or accelerations) were found to be significant (p<0.05). Lastly, for one fifth of linear regressions, the slope of the regression was negative, indicating increased discomfort was not always related with increased breast displacement or acceleration.

## DISCUSSION

This study measured the performance of 5 sports bras at reducing undesirable and uncomfortable breast kinematics when participants engaged in 5 whole body motions which can frequently be encountered in exercise activities. Bras demonstrated varying effectiveness at reducing kinematics across the exercises tested. For most performance outcomes in vertical direction, the relatively more recently developed bra tended to reduce kinematic outcomes more than the other bras. For example, when significant differences between the bras detected, the newer bra provided 31% greater reduction in vertical displacement on average than other bras. Likewise, the newer bra reduced vertical acceleration by 31% more on average than other bras. Across the outcomes and directions, this bra generally reduced the undesirable displacement and acceleration more consistently than the other bras as evidenced by the greater number of bra pairwise differences detected for the newer bra (Tables 2 and 3). For lateral kinematic outcomes, the effect of the bras was not as pronounced and generally less consistent. When bra performance was evaluated in terms of comfort and ease of use, the more recently developed bra was rated better than the other bras in terms of performance and ease of use, but there were no differences in terms of how the bras felt, or in terms of pain and comfort. The results that the relatively newer style bra was as good or better than existing bras from more well established companies suggests that development of bras which result in reductions in undesirable motion and are more comfortable and easier to use is possible in the future.

As nearly identical techniques were utilized for the measurements, the magnitudes of kinematics measured in this study compare favorably to those determined in previous studies (2, 12, 14). An interesting and relevant result of this study was that for some exercises and bras, including all bras for the running condition, participants were able to exercise more effectively as indicated by the greater performance velocity. This finding suggests there is potential for performance enhancement with wearing bras as compared to the bra-less (Control) condition. Although whole body segment kinematics were not measured in this study, a previous experiment found differences in segment kinematics from different levels of breast support; higher breast support resulted in more economical running kinematics (8). These findings together suggest that, depending on the exercise, it is possible that segment control could be altered in order to optimize movement efficiency, which might ultimately lead to more effective running or exercise motion, and thereby faster performance.

Similar to previous studies which sought to find significant relationships between comfort and measured breast kinematics (12, 14) the current study also did not find consistent significant relationships between comfort and breast displacements, velocities, or accelerations. In the present study, when evaluating the lack of significant correlations between kinematic measurements and perceived bra performance, this finding can be interpreted as increased comfort was not always perceived when wearing a certain bra even though reductions in kinematics were large. This lack of a relationship between comfort and kinematics is noteworthy in that it suggests selection of bras is individual specific; not all prefer bra with best support in terms of reduced kinematics. Some previous studies have found relationships between comfort and breast velocity (14), or suggested that breast discomfort may be related to velocity, at least

when exercising in water where velocities are significantly reduced compared to normal conditions (6). It is possible that for certain situations, discomfort is related to not only kinematic measures but also kinematics combined with psychogenic or psychosomatic factors. In a related manner, a previous study found perceptual ratings of fit and comfort tended to better predict breast pain rather than measured displacements (12). Furthermore, it is important to note there may be other unintended effects other than breast support from wearing of a bra. These effects may be positive or negative and may relate to the bra preference and perceived comfort. For example, previous studies have found increased breast support results in torso and arm kinematics which are more closely aligned with economical running (8). However, the bra supports not just the breasts but other body segments. Therefore, it still remains unclear if the more economical kinematics are related to breast support provided by bras, or the effects of wearing the bra on other elements of the body including muscles and related proprioception similar to the manner in which braces have been shown to provide benefit, e.g. (1). For example, the bras tested here supported the breasts with straps quite similar to scapular taping which has been shown to effect kinematics, electromyography and proprioception of the shoulder joint and associated muscles (4). More work is required to understand how bras may affect the entire body, including kinematics of segments proximal and distal to the breasts, in order to understand the causation of any effects on performance and overall comfort.

Although this study employed exercise test durations typical of prior studies, the test duration was relatively short. Shorter test duration has been shown to result in different measurements compared to longer durations (9). Although the same exercises were performed for the same time durations, the speed of performance was not controlled or standardized, but rather instructions were to exercise at self-selected comfortable pace.

In summary, this study provides comprehensive evaluation of sport bra products in terms of their ability to reduce breast motion. The results suggest that the relatively new approach, may be more effective than other, more renowned competitors. However, all bras are somewhat less effective and less consistent across exercises at reducing displacements and acceleration in the lateral direction. This finding means there is potentially some room for future improvement in the design of the bra to improve bra performance in reducing undesirable kinematics in the medial-lateral direction.

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